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STATUS REPORT NO. 4 ON

CLINCH RIVER STUDY

Editor
R. J. Morton

NOTICE

OAK RIDGE NATIONAL LABORATORY

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U.S. ATOMIC ENERGY COMMISSION

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Errata

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Page 85, Table 13, Line 3 (Kingston Steam Plant).-
In Column 2 change to Emory R. instead of Clinch R.;
and in Column 3 change to <u>Near</u> <u>CRM 4.4</u> instead of
<u>CRM 3</u>.

Page 86, Paragraph 3, Lines 5 and 6.- In line 5 of
the Paragraph add "(3)" after "Steam Plant;", and in
line 6 add "(4)" after first word so as to read:
"and (4) TRM 465.5--."

Page 86, Paragraph 4, Lines 1 and 2.- Change to read:
"Water supplies taken from the Clinch River at CRM 14.5
and from Emory River in the vicinity of CRM 4.4 are
used by ORGDP and ------."

Page 99, Equation (3).- In second parentheses change
to "+" instead of "=" so that equation reads:

$$E_i = 0.33 \text{ Em } f \left(1 - \frac{\sqrt{z}}{50}\right) \left(1 + \frac{\sqrt{Em}}{4}\right).$$

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HEALTH PHYSICS DIVISION

STATUS REPORT NO. 4 ON CLINCH RIVER STUDY

Clinch River Study Steering Committee

EDITOR

R. J. Morton

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FEATURES OF THE OVER-ALL PROGRAM

In three previous status reports, progress reports covering the study program through October 1961 were summarized.[1,2,3] This fourth status report is based primarily on progress reports for the period November 1961 to April 1962, submitted at meetings of the Clinch River Study Steering Committee April 25-26, 1962.

As described in the earlier status reports,[1,2,3] the Clinch River Study is a cooperative research program in which several agencies are active participants (see pages x and xi). The purpose is to improve knowledge of prevailing conditions, relevant phenomena, and potential health hazards in the Clinch and Tennessee river systems with respect to radioactive contamination. Over-all responsibility for the program rests with the Steering Committee (see page viii). This committee has developed basic plans and policies and exercises general supervision over all phases of the study. Specific study projects are carried out by members of the study staff with principal headquarters and facilities at the Oak Ridge National Laboratory (ORNL).

The basic objectives of the study are: "(1) to determine the fate of radioactive materials currently being discharged to the Clinch River, (2) to determine and understand the mechanisms of dispersion of radionuclides released to the river, (3) to evaluate the direct and indirect hazards of current disposal practices in the river, (4) to evaluate the over-all usefulness of this river for radioactive waste disposal purposes, and (5) to recommend long-term monitoring procedures."[3]

Steering Committee Actions

The steering committee held an open meeting at ORNL April 25-26, and an executive meeting on April 26, 1962. The open sessions were conducted as an information meeting for members of the committee, subcommittees, and study staff, at which progress reports were presented and discussed. The purpose of the executive meeting was for the steering committee and group leaders to consider and to make decisions concerning specific questions and proposals.

The open sessions, April 25-26, were attended by a total of 36 persons. Twelve summaries of the results of particular work projects and four progress reports by subcommittees were presented and discussed briefly as follows:[4] (1) "Area Monitoring of Clinch River" by H. H. Abee (ORNL); (2) "Management and Control of Liquid Waste at ORNL" by E. J. Witkowski (ORNL-Operations Division); (3) "Study of White Oak Creek Drainage Basin" by T. F. Lomenick (ORNL); (4) "Hydrologic Measurements and Analyses" by three speakers: (a) "Effect of Power Releases from Norris Reservoir on Flow and Radioactivity Levels in Clinch River," "Effect of Power Releases from Melton Hill Reservoir on White Oak Lake Levels," and "Proposed Investigation in Bear Creek Basin" by P. H. Carrigan (USGS-ORNL); (b) "Data Collection and Analysis Program" by J. P. Monis (USGS); and (c) "Radiotracer Study in the Clinch River, February 1, 1962" by B. J. Frederick (USGS); (5) "Study of Density Gradient Separation of Particulate Matter from River Water" by W. T. Lammers (TVA-Davidson College); (6) "Data from Public Health Service (USPHS) Environmental Surveys--Sediment Samples Collected in May 1961" by A. G. Friend (USPHS); (7) "Progress Report of Subcommittee

on Water Sampling and Analysis" by M. A. Churchill (TVA), chairman;
(8) "Progress Report of Subcommittee on Bottom Sediment Sampling and
Analysis" by P. H. Carrigan (USGS), chairman; (9) "Progress Report No. 1,
Subcommittee on Aquatic Biology" by S. I. Auerbach (ORNL), chairman;
(10) "Data from USPHS Environmental Surveys--Fish Samples Collected in
May and December 1961 and March 1962" by D. B. Porcella (USPHS);
(11) three progress reports on Studies in Aquatic Biology: "Additional
Data on Strontium in Clams," "Biological Half-Life of Cesium in Fish,"
and "Radioactive Strontium in Fish used for Human Food" by D. J. Nelson
(ORNL); (12) "Progress Report of Subcommittee on Safety Evaluation"
presented by R. L. Hervin (AEC) in the absence of C. P. McCammon (TDPH),
chairman. Finally, a discussion on "Future Plans" was led by F. L. Parker,
who suggested an outline of further work needed for consideration by
the steering committee.

At the executive meeting April 26, 1962,[5] criteria for release
of talks, papers, and publications based on data from the Clinch River
study that have not been previously released in a publication by the
steering committee were considered. The following restatement of
the committee's policy was adopted:

1. Presentation of a paper or talk containing data from the
Clinch River study not previously published in a status report must
have the approval of the chairman of the steering committee before
presentation.

2. Publication of a paper or report containing data from the
Clinch River study not previously published in a status report must
be approved by a majority vote of the steering committee members
prior to publication.

Releases of two proposed papers were authorized, namely:
"Proportional Sampling for Radionuclides in the River System below
Oak Ridge" by M. A. Churchill for presentation at the annual meeting
of the American Geophysical Union in Washington, D. C. on April 27, 1962,
and for publication in the proceedings of the meeting; and "Studies on
the Distribution of Radionuclides in the Clinch and Tennessee Rivers
below Oak Ridge" by A. G. Friend and D. B. Porcella for presentation
at the 1962 Nuclear Congress in New York, N. Y. on June 6, 1962.

The steering committee authorized preparation and issue of
Status Report No. 4 (the present report). Subcommittee chairman and
staff investigators were requested to cooperate in the preparation of
text, tables, and figures. It was agreed that most of the progress
reports submitted during the open meeting were suitable and should
be condensed and included in Status Report No. 4.

The role and working procedures of the four subcommittees were
considered carefully. It was the consensus that current information
about the program is necessary as a basis for steering committee
functions, and that to be of most value such information should be
provided while the data are being assembled and progress reports being
prepared by the several subcommittees. It was requested that each
subcommittee should develop a consolidated summary of available data
pertinent to its area of study as soon as feasible, and assist in
bringing these summaries together so as to provide a clear and
comprehensive picture of the over-all status of the program. The
committee recognized the large amount of time required for a subcommittee
to assemble, condense, and evaluate information, particularly the

Subcommittee on Safety Evaluation, and agreed that every possible effort should be made to provide staff assistance to the subcommittees.

The committee voted to appoint a "study coordinator" with broad responsibility to work with the subcommittees and the staff of the study. His function will be to coordinate and guide the various phases of the work program so as to achieve the essential objectives of the study by the time the program is completed. F. L. Parker was designated to serve as Study Coordinator.

The committee considered the need to expand the study program by accelerating studies already in progress or initiating work on other problems. It was agreed that additional manpower which might be available from time to time in one or more of the participating agencies could be used advantageously for this purpose. It was the consensus that additional manpower would be helpful on: (1) mineral-sorption studies to accelerate work on river sediments and radionuclide retention; (2) a fish collection and analysis project which would require intensive work in order to provide data needed by the Subcommittee on Safety Evaluation; and (3) extension of water sampling and analyses, for example, on small streams, which might help to explain high ruthenium activity upstream from the Laboratory. The committee invited the assignment of suitably competent personnel for work on these problems.

It was agreed that the safety of the river system as now operating must be appraised as adequately as possible since this is one of the five basic objectives of the study. To obtain information on undefined aspects it was suggested that the present staff might make some limited

but specific investigations. For example, additional survey data and sampling are needed to indicate the importance and potential hazards, if any, of irrigation of crops with river water. Also, whole-body counting of a sample of workers at ORGDP was recommended to determine whether body burdens of radionuclides in these users of Clinch River water are measurable and significant.

The committee discussed but left for later consideration the value of data which might be obtained by analysis of samples of raw and finished water from the water plant of the Oak Ridge Gaseous Diffusion Plant (ORGDP), and also from existing shallow wells downstream near the Clinch or Tennessee Rivers. The Subcommittee on Safety Evaluation desired further data on contaminants in drinking water to aid in its evaluation of potential exposures through this medium, but there was doubt whether data obtained from sampling of existing wells or the ORGDP water supply would be definitive.

Arrangements were authorized for the next regular meeting of the steering committee to be held at the USPHS Sanitary Engineering Center at Cincinnati, Ohio. A meeting at this center would enable committee members to become more familiar with analytical methods employed and correlative research being conducted by the USPHS.

ASSESSMENT AND CONTROL OF WASTE DISCHARGES

In order to define and evaluate radioactive contamination in the Clinch River and farther downstream, specific knowledge of the sources, quantities, characteristics, and variability of wastes released to the river is essential. Conclusions regarding potential hazards from radionuclides in the river system and recommendation of long-term monitoring procedures are two of the basic objectives of the Clinch River study. To be realistic the bases for these conclusions and recommendations must include quantitative data on waste releases, and judgment as to the effectiveness of measures for their control at the source.

At ORNL the management of radioactive wastes and the provision of waste disposal facilities are responsibilities of the Operations Division. Environmental studies of waste discharges from individual sources to the White Oak Creek drainage system and through the creek system to Clinch River are conducted by the Radioactive Waste Disposal Research Section of the Health Physics Division. Reports by these two groups, presented April 25, 1962 for information to the steering committee, are summarized below.

Management of Liquid Wastes at ORNL[*]

Introduction

The primary responsibility for radioactive releases from ORNL into the environment lies with the many people who handle radioactive

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[*]Based on a discussion by E. J. Witkowski, Operations Division, ORNL at open meeting of the steering committee, April 25, 1962.

materials in laboratory and processing areas. Two liquid and two gaseous waste disposal systems are provided and the amounts of radioactivity that escape into the environment depend mainly on how the people at the source use these systems. The function of the Operations Division group is to operate the waste collection and transfer equipment, maintain the systems in good operating condition, educate the many users of the sytems, and police them to be sure that the systems are properly used. The greatest contribution of this group is in educating and policing users of the systems. The facilities provided and the work done in disposing of liquid wastes will be reviewed briefly. A detailed description of the history of waste management at ORNL and of the facilities and methods for liquid waste disposal through 1958 was included in a report by Browder et al, in 1959.[6]

Intermediate Level Waste

A simplified flow diagram of the two liquid waste systems is shown in Fig. 1. It may be noted that no high-level waste is shown. The term high-level is reserved for future wastes that will run in excess of 10 curies per gallon; and there are no such wastes in the Laboratory at the present time.

Practically all of the radioactivity in liquid wastes generated at the Laboratory—all but a fraction of 1 per cent of the total—is handled through the intermediate level system. The process-waste system under ideal conditions would carry no activity. Its main purpose is to collect process water that may become contaminated in the event of equipment or human failure. One of the main jobs of the Operations Division group is to get people to keep down the volumes

LIQUID WASTES
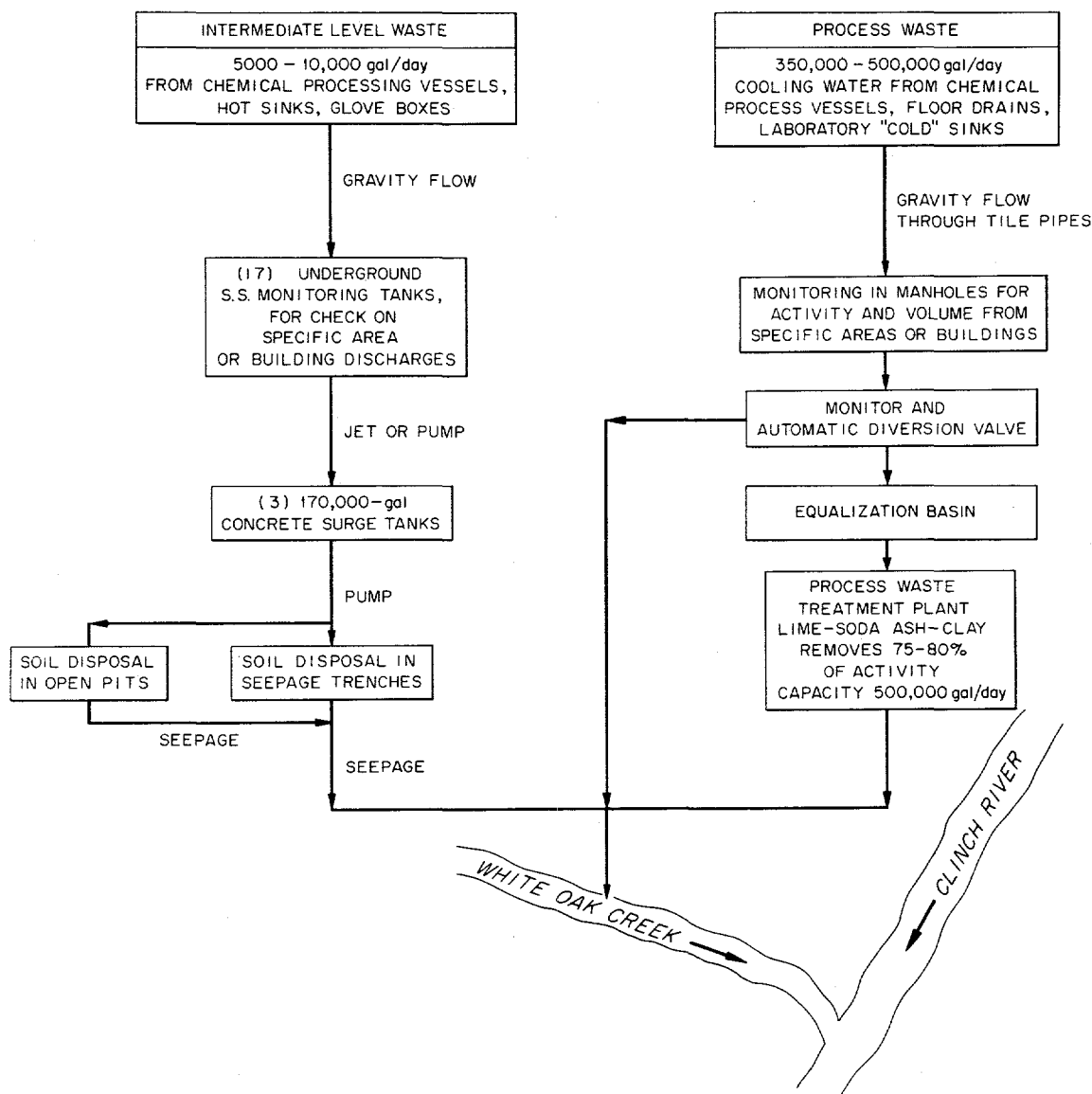
Fig. 1. Flow Diagram of Laboratory's Liquid Waste Systems.

of their radioactive liquid wastes to the lowest possible level and to discharge them into the intermediate-level system.

The intermediate-level waste is collected in 17 underground monitoring tanks. These tanks are used for collection and temporary storage, for neutralizing acid wastes with caustic, and for separating the wastes according to the various people who generate them. It has been learned over the years that the "customers" cannot be depended upon to neutralize their own wastes. Two tanks were lost through corrosion before it was decided that the Operations Division group should add its own caustic. It has also been learned that unless the wastes from the various research groups are separated so that the discharges can be identified with the responsible individuals, people become careless and allow excessive dilution of their wastes.

The volume of liquid is continuously measured and the information telemetered to the Waste Control Center where all of the Operations Division's waste disposal data are recorded. An operator there can detect any abnormal rise of the level in the monitoring tanks and he gets in touch with the customers. Most frequently the trouble may be that the user of the system forgot to close a water faucet in a hot sink and is not aware of that fact. The operator's contact induces him to shut off the water before the waste system becomes overloaded.

The waste is pumped from the monitoring tanks through a number of stainless steel lines to three large underground concrete tanks; and from there it is pumped through an underground cast-iron

pipeline, 2-in. dia and 1 1/2 mi long, to the waste-disposal open pits

and covered trenches. At the present time, approximately one-half of

the waste goes to the pits and one-half to the trenches. The details

of the operation of the pits and trenches will not be discussed here.

Another covered trench is now being designed which will eliminate the

use of the open pits. In choosing between pits and trenches the

trenches are considered the lesser of two evils. It is hoped to

eliminate both by the end of 1963 when the waste evaporator now

being designed is put into operation.

Process Wastes

As mentioned previously, process wastes are mainly water that

may become contaminated in the event of an accident, and, under ideal

conditions, should carry no radioactivity. The fact is, however,

that more than five curies of activity per month are discharged into

this system of which less than two curies per month are released into

the creek. This is because the rule prohibiting normal discharges

of activity into this system is relatively new and many users

have not yet altered their operations to conform to this rule. A

great deal of progress has been made, however. At one time the

Laboratory discharge to the creek averaged five curies per day.

Now it averages less than two curies per month, and about 75 per cent

of the total release comes from two sources which it is hoped will be

eliminated before the end of this year.

The process waste system resembles a sanitary sewer system.

The waste from the laboratories and operating buildings is collected

and transferred to a common point by means of underground

tile pipelines. Each of the eight main tributaries has a monitoring station at which the activity and flow are measured and samples proportional to the flow are collected. The flow and activity measurements are telemetered to the Waste Control Center so that the operator may immediately get in touch with those who produce the wastes when he notices abnormal activity or flow in the waste streams. At the diversion box, the junction of all the streams, the combined flow and activity are also measured and this information is telemetered to the Waste Control Center. A proportional sample taken at the diversion box is analyzed every 4 hours to be sure that the instruments are in good operating condition. Samples from the tributary streams are not analyzed unless the analytical results will help in locating the source of an unusual discharge.

The controls at the diversion box can be set so that, in case the waste volume exceeds the capacity of the plant, any wastes that are below a predetermined level of activity will be automatically bypassed without treatment. This has not been necessary for almost a year and a half, since the volumes have been reduced below the plant capacity and all of the waste can now be processed. The equalization basin provides reserve storage for emergency handling of excess volume and high activity which might conceivably occur at the same time.

The process waste treatment plant removes only 75-80 per cent of the activity. This is not sufficient to meet the Laboratory's long-range goal of reducing the activity of discharges into Clinch River to MPC levels. It may be necessary to add more waste processing equipment, and some development work on resin columns for use in the process waste system is now in progress. The Operations Division workers are hopeful that the Laboratory's goal can be attained by better

controlling and reducing the discharges into the system; and believe that this approach should be given a thorough trial before a large expenditure of money for more equipment is made.

Monitoring of Creek

Besides the intermediate-level waste pits and the process waste system which routinely release activity into the creek, there are several other potential sources. Radioactive materials may accidentally get into the creek through the sanitary sewer system, through the storm sewer system, and from the solid waste burial grounds. To keep up with these potential releases a number of monitors have been set up along White Oak Creek (see Figure 2). The monitoring stations are numbered 1 through 5. Each measures and integrates the flow and takes a proportional sample for activity-inventory purposes. Stations 4 and 5 sample the activity seeping out of the open waste pits. Station 3 samples the stream below the homogeneous reactor site (HRT) and burial ground no. 5. Station 2 samples White Oak Creek below burial ground no. 4 and all discharges from the main Laboratory area, including effluent from the process waste system. Station 1 samples the discharges from the process waste system. The activity discharged from the storm sewers, burial ground, and sanitary sewers is indicated by the differences between stations 2 and 1. This method of determining the activity from the miscellaneous sources is not satisfactory because small releases from the sources would be below the limits of analytical accuracy. It is hoped to correct this in the future by installing another monitoring station in the creek east of the settling basin.

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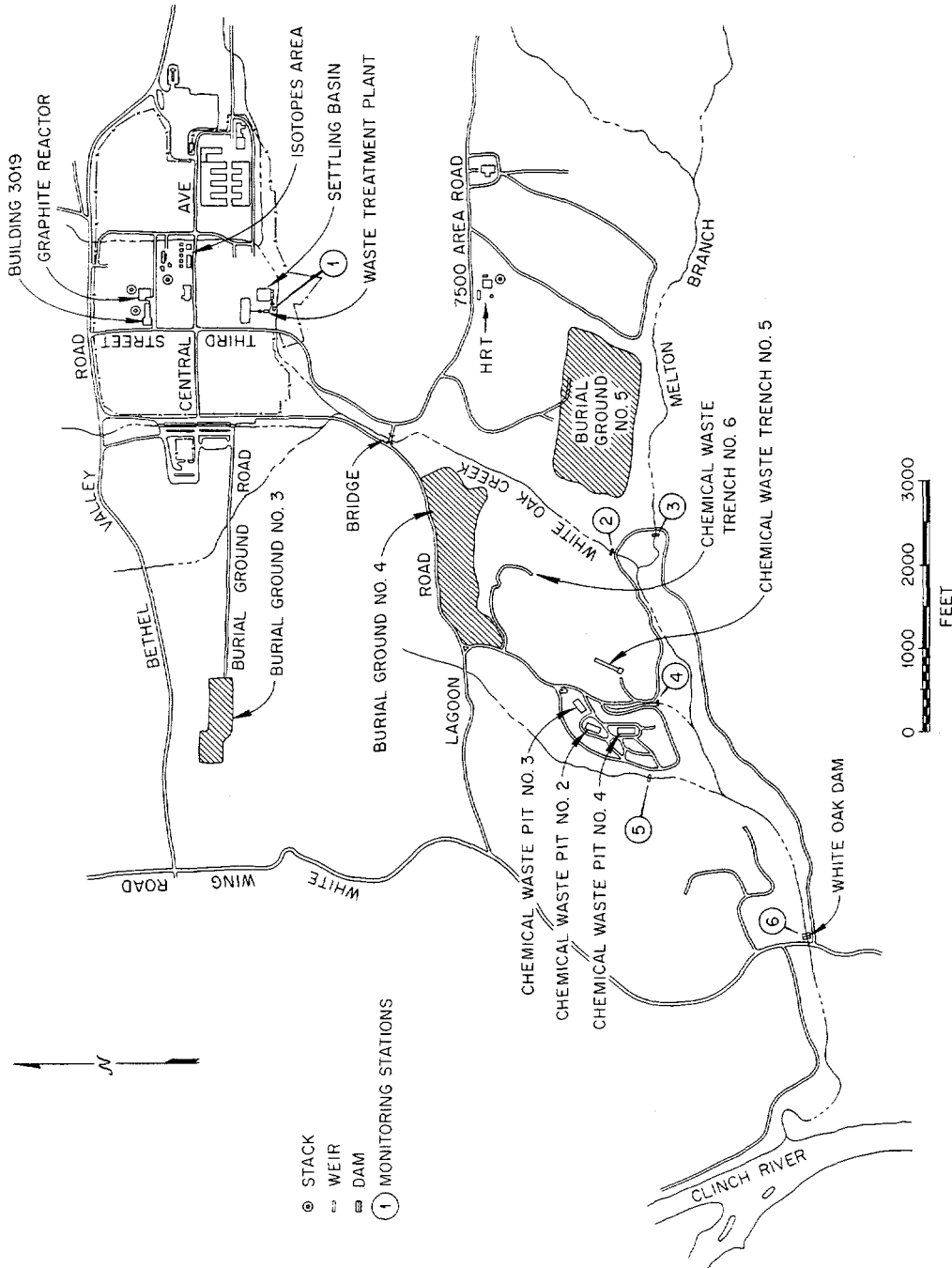
Fig. 2. Location Plan for Laboratory's Waste Monitoring Stations.

The total discharge through White Oak Creek to Clinch River is sampled and measured by the Health Physics Division at White Oak Dam (station 6).

In addition to these sampling stations, direct radiation monitors have been installed in the sewage disposal plant effluent line and in the creek at the 7500 area bridge. The information from the monitors is telemetered to the Waste Control Center so that any significant activity discharged from the sewage disposal plant or storm sewers will be immediately noticed by the operator. The direct radiation monitor in the sewage disposal plant effluent is adequate since normally this stream is completely free of activity. The monitor at the bridge however, measures the discharge from the process waste system along with any small discharges from the storm sewers so that very small releases could not be detected. To correct this it is planned to put a direct radiation monitor, along with the additional sampling station, in the creek east of the process waste treatment plant discharge, and two direct radiation monitors on two small waste streams in the east end of the Laboratory area.

Accumulation and Movement of Radionuclides in White Oak Creek Basin*

Introduction

For the past 20 years radioactive materials have been discharged into the surface streams, soils and rocks, and the atmosphere at the Oak Ridge National Laboratory. A large part of the activity has remained at disposal sites; some has moved from one part of the disposal complex to another; and, finally, significant quantities of fission products have moved from the controlled environment of the Laboratory

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*Based on a discussion of "Study of White Oak Creek Drainage Basin" by T. F. Lomenick, Radioactive Waste Disposal Research Section, ORNL at open meeting of the Steering Committee, April 25, 1962.

into the Clinch River.

Currently the Laboratory releases low-level waste water, most of which is pretreated, directly to surface streams. Intermediate-level liquid waste is pumped to seepage pits excavated in the soil; solid waste is buried in unlined earthen trenches; and gaseous waste, after treatment, is discharged through tall stacks to the atmosphere. The fate of the radionuclides in these wastes is of vital concern, since the over-all usefulness of the environment for planned discharges, as well as an assessment of the hazards to man from accidental releases of radioactive wastes, depends on the distribution, retention, and rates of movement of radionuclides in and through the system.

The White Oak Creek Drainage Basin includes all ORNL facilities that contribute significant quantities of radioactive waste to the environment. Investigations are now under way at the Laboratory to identify and define the various contamination sources within the basin and to examine geohydrological factors that affect the transport of radionuclides through the soil and in surface streams.

Sources of Contamination

General.--There are 23 known sources of radioactive contamination in the White Oak Creek drainage basin (see Fig. 3). The creek receives directly the discharges of partially-treated process waste water, laundry water, sanitary sewage, and reactor retention pond effluents, and, eventually, seepage from six intermediate-level waste seepage pits and five solid waste burial grounds. Runoff from land surfaces, which are subjected to local fallout from four tall stacks and to general fallout, also contributes some activity to the creek. In addition some radio-nuclides enter the creek from the beds of former White Oak Lake and intermediate pond.
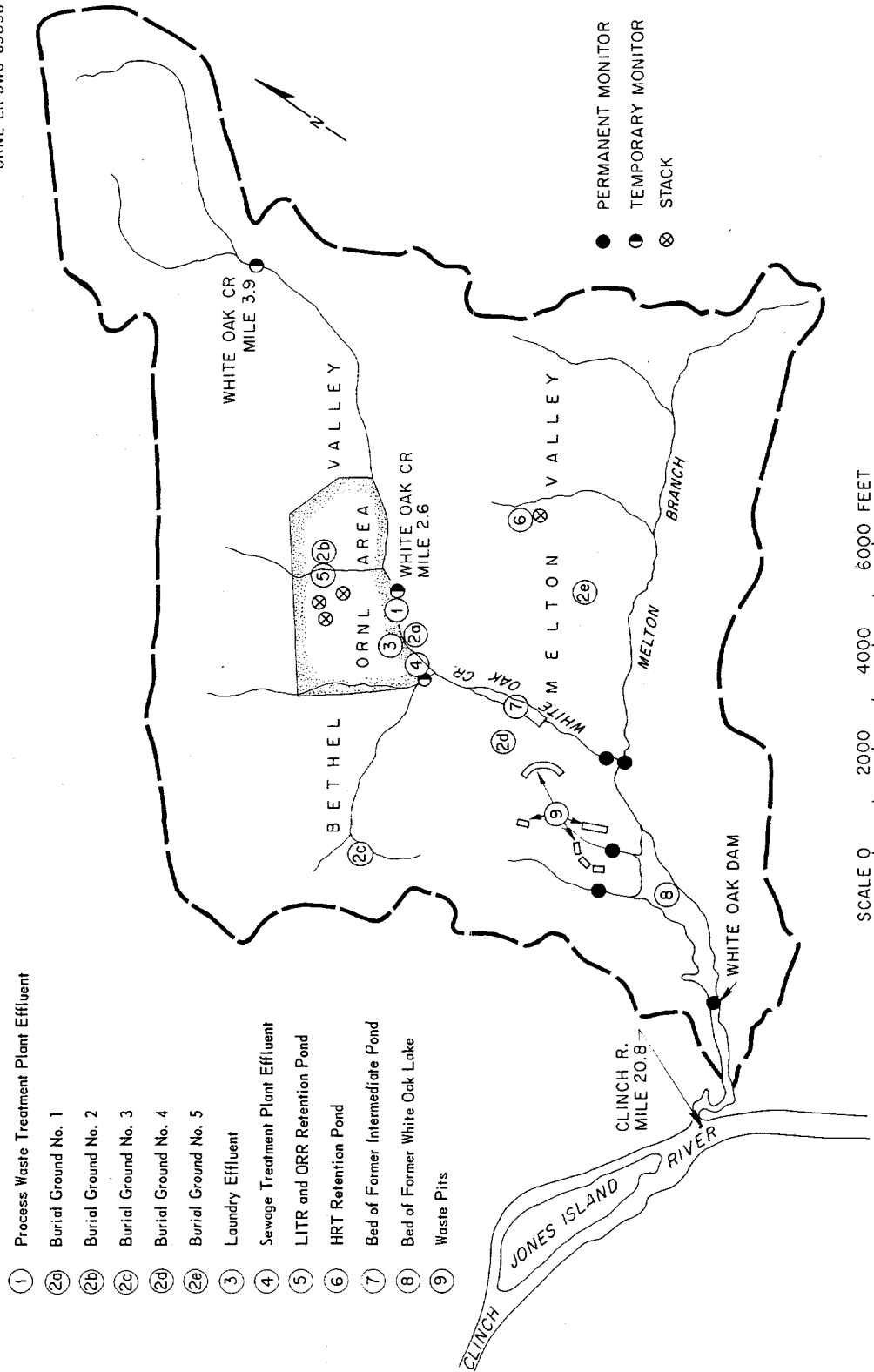
Fig. 3. Map of White Oak Creek Basin Showing Sources of Radioactive Contamination and Location of Stream Monitoring Stations.

Techniques and Equipment Employed in Assessing Sources.--

Permanent water sampling stations now exist on White Oak Creek at

White Oak Dam and at mile (WOCM) 1.8, on each of the two streams that

drain the intermediate-level waste seepage pit area, on Melton

Branch just upstream from its confluence with White Oak Creek, and

on the effluent from the Process Waste Water Treatment Plant (PWWTP)

(see Fig. 3). These stations, which employ proportional sampling

devices, provide information primarily on the amount and type of

activity that is discharged to the Clinch River and that which

leaves the major contamination sources at ORNL. Three temporary water

sampling stations were established on White Oak Creek at WOCM 2.6

and 3.9 and on the tributary stream that drains the northwest portion

of the area (see Fig. 3). These stations help to determine the

amount and type of activity contributed to the system from fallout,

burial grounds, and other sources in Bethel Valley that could not be

monitored directly. In addition, these stations have provided

information on the chemical composition of the creek water, transport

of sediments, and volume of flow in the creek. Representative samples

of the effluent from the laundry and the sewage treatment plant were

also taken, and a contaminated storm sewer that discharges into

White Oak Creek downstream from the station at WOCM 2.6 in Bethel

Valley was monitored.

Because of the relatively high degree of contamination in

White Oak Creek below the PWWTP, it is extremely difficult to detect

small quantities of waste that may seep directly into the creek

from Burial Ground 4 and the beds of former White Oak Lake and

intermediate pond. A previous study of Burial Ground 4 has shown that

radionuclides are leached from the burial waste and transported by ground water through the soil to points of discharge in or near surface streams.[7] However, the amount of activity that reaches White Oak Creek from this source is so small in comparison to the amount already in the creek that it is undetectable. Detailed geologic and hydrologic studies in the beds of former White Oak Lake and intermediate pond are incomplete, but preliminary data indicate little movement of radionuclides associated with sediments at these sources.

The water sampling instruments at the creek stations and sewage treatment plant consist of battery-operated devices with rotating scoops that collect a sample once every 15 minutes. The amount of sample taken is directly proportional to the flow over a weir or through a Parshall flume. By use of water-level recorders, a continuous record of the discharge at each station is obtained. The sampling stations at the northwest tributary and at WOCM 3.9 are shown in Figs. 4 and 5, respectively.

Creek Contamination

A summary of radioactivity released to the creek from the various sources of contamination for the period May-December 1961 is shown in Table 1. It may be noted that the PWWTP is the largest single contributor of Sr^{90} and Cs^{137} to the creek, but seepage from the waste pits accounts for practically all of the Co^{60} and Ru^{106} in the system.

During the 8-month sampling period the sewage treatment plant contributed approximately 197 mc of Sr^{90} to the creek. Although this amount is small in comparison to that released from the PWWTP, it is rather large for a facility that should be free from
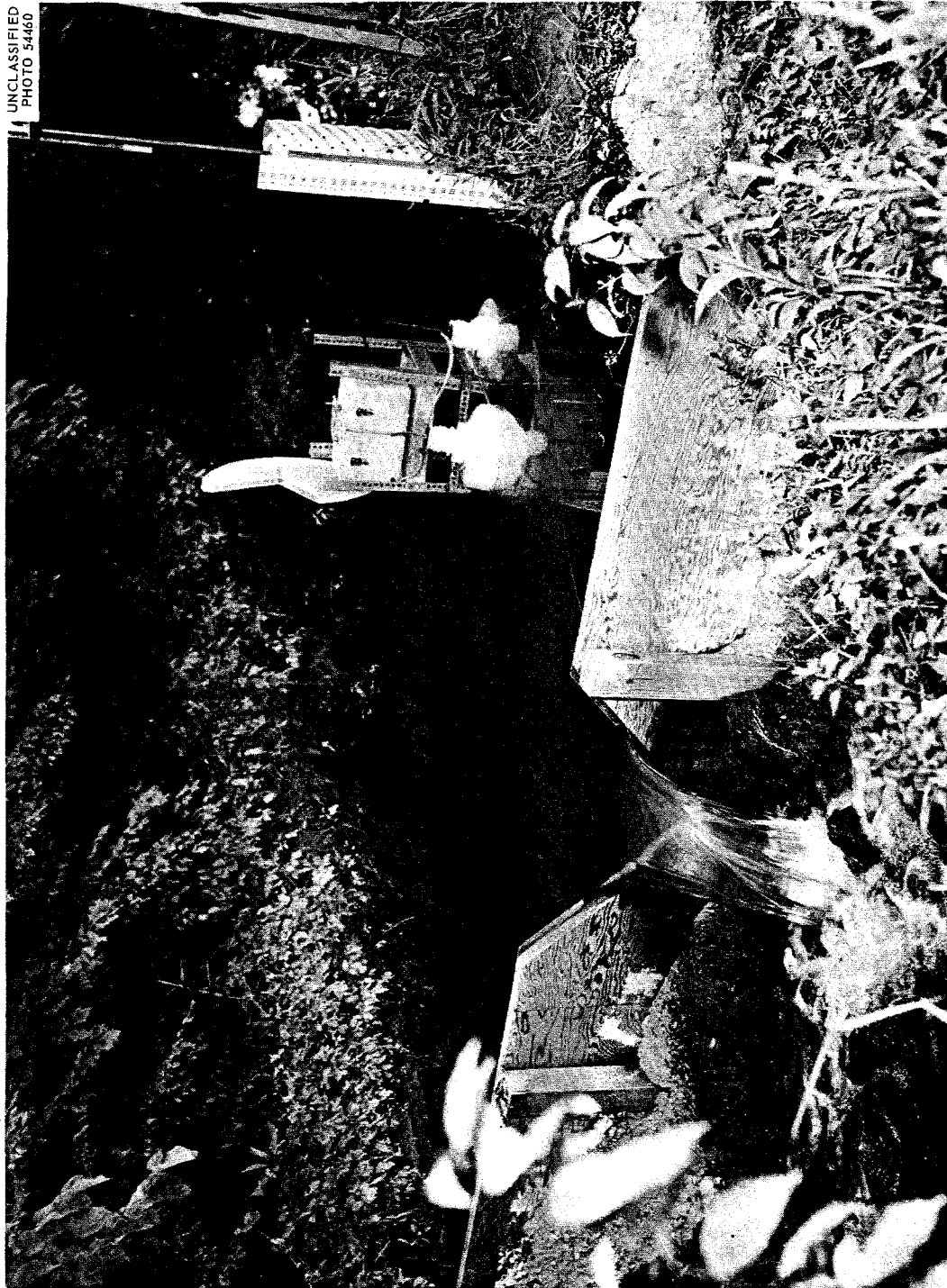
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Fig. 4. V-Notch Weir, Staff Gage and Stilling Well, Scoop Sampler, and Collecting Bottles at Northwest Tributary Sampling Station.

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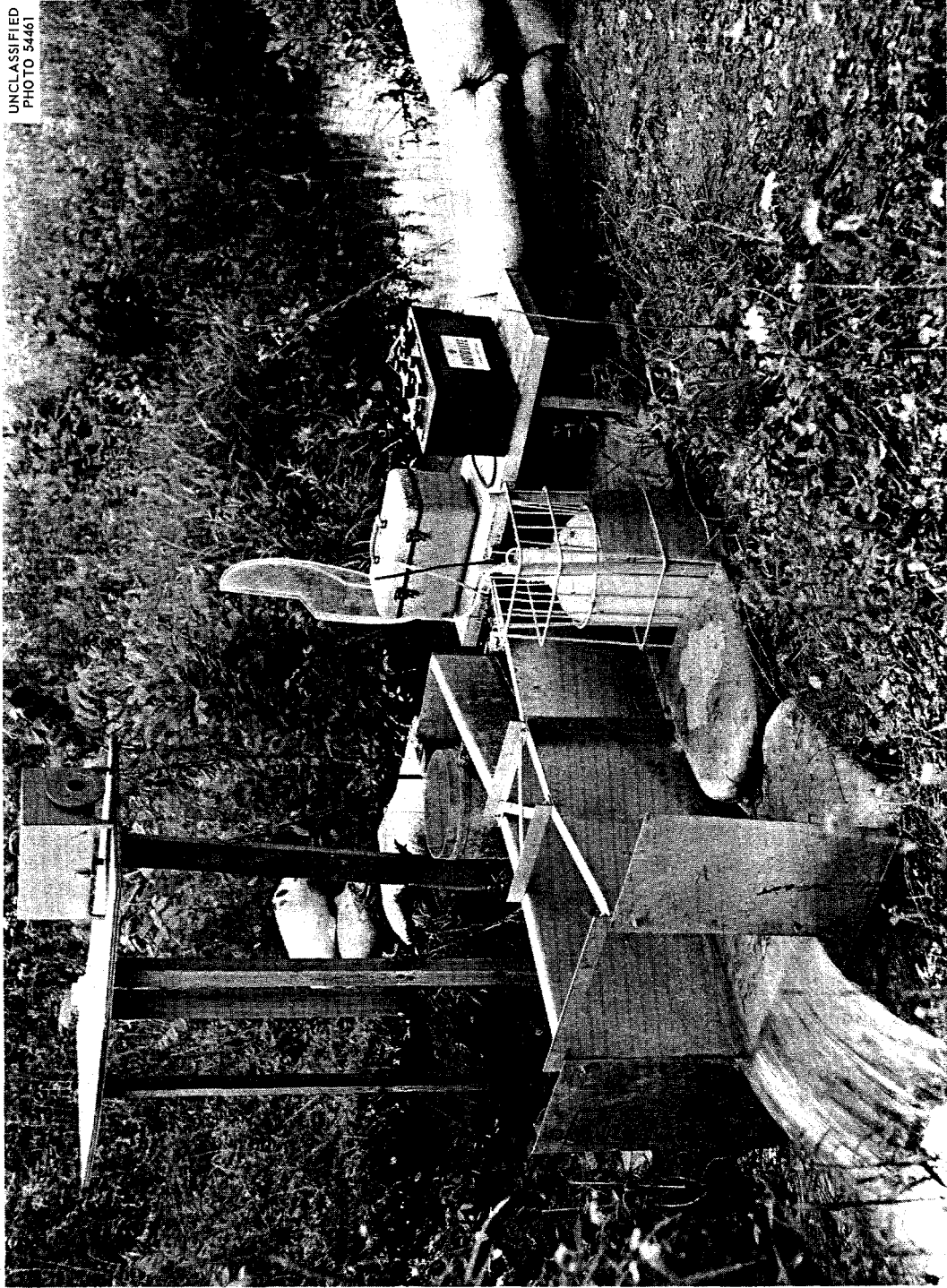
Fig. 5. Parshall Flume, Stilling Well and Float Recorder, Scoop Sampler, and Collecting Bottle at WOCM 3.9 Sampling Station.

Table 1. Radionuclides Released to White Oak Creek
May-December 1961

	Sr^{90}		Cs^{137}		Co^{60}		Ru^{106}	
	mc	%	mc	%	mc	%	mc	%
Process Waste Water Treatment Plant (PWWTP)[c]	4200	63.93	1120	50.82	443	.67	416	< .01
Sanitary Sewage	197	3.00	37	1.68	7	.01	7	< .01
Laundry	11	.17	22	1.00	8	.01	3	< .01
Watershed above Northwest Tributary Station	61	.93	31	1.41	1	<.01	11	< .01
Watershed above Station at WOCM 2.6	170	2.59	187	8.48	94	.14	43	< .01
Storm Sewer below PWWTP in Bethel Valley[a]	1135	17.27	127	5.76	208	.31	68	< .01
Watershed above Melton Branch Station[c]	782	11.90	205	9.30	289	.43	5207	.07
Waste Pits[b,c]	14	.21	475	21.55	65,000	98.42	6,838,000	99.92
Totals	6570	100.00	2204	100.00	66,050	100.00	6,843,755	100.00

[a]Values based on quantities detected April-October 1962.

[b]Values represent quantities released from pits.

[c]Values from Operations Division, ORNL

contamination. The mean concentration of Sr^{90} in the sewage treatment plant effluent was 1.7×10^{-6} µc/cc or about 40% of MPC_w for 40 hr/wk occupational exposures.

About 3000 lb of contaminated clothing is washed and decontaminated each week at the laundry. All wash water from the laundry drains into a storm sewer which in turn discharges into White Oak Creek. As seen in Table 1, the amount of activity released from this facility is small.

Included in the drainage area of the northwest tributary stream, which comprises approximately 16% of the total area of the White Oak Creek drainage basin, are Burial Ground 3 and the extreme northwest portion of the ORNL plant site. Approximately 34% of the White Oak Creek watershed is located above the sampling station at WOCM 2.6. Burial Ground 2 and the retention pond of the Low-Intensity Test Reactor (LITR) and Oak Ridge Research Reactor (ORR) are within this area. The drainage area of the sampling station at WOCM 3.9, which comprises about 13% of the White Oak Creek watershed, does not contain any ORNL facilities or waste disposal areas. Thus, the activity detected at this station is the result of rainfall and surface runoff which leach and transport soils contaminated by Laboratory and general fallout (approximately 3 curies/sq mi/year). By assuming that the amount of Sr^{90} that reaches White Oak Creek from the watershed above the stream sampling station at WOCM 3.9 is representative of the entire drainage system, it is calculated that about 15 millicuries of Sr^{90} or less than 0.5% of the total entering the creek for the period May-December 1961 is due to fallout. Contamination detected at the other stream-sampling stations includes that associated with fallout,

discharges or seepage from known sources within the drainage areas, and sources that are as yet unknown or undefined.

Relatively large quantities of Sr^{90} were detected in the drainage from a storm sewer that empties into White Oak Creek below the PWWTP in Bethel Valley. The activity enters the storm sewer in the vicinity of the equalization basin of the PWWTP, but at present the actual source is not known.

Until July 1961 the Homogeneous Reactor Test (HRT) facility routinely released liquids containing fission products to Melton Branch, a tributary to White Oak Creek, and gaseous waste through a tall stack to the atmosphere. Although waste products do not now enter the environment directly from these sources, past releases have contaminated the stream bed below the facility and, consequently, leaching and scouring of the creek bed cause activity to continue to move from the area.

Currently, several thousand curies per year of ruthenium flow onto the bed of former White Oak Lake from the waste pits. As the waste water traverses the lake bed, more than half of the ruthenium is removed from solution. A recent investigation has shown that most of the movement of ruthenium across the lake bed is due to surface flow and only a small fraction of the ruthenium that enters White Oak Creek from the lake bed is transported by ground water through the lake-bed soil into the creek.[8] The ruthenium that is not sorbed moves at such a slow rate through the soil that radioactive decay reduces the concentration reaching the creek to insignificant proportions. The amount of surface flow and consequently the quantity of ruthenium

that reaches the creek from the lake bed varies seasonally. During
the dry summer months, drainage from the waste pits recharges the
ground water in the lake bed. Thus, there is little surface flow
and consequently little ruthenium is transported into White Oak
Creek. However, in the wet winter season surface runoff from
the lake bed is high and larger amounts of ruthenium enter the
creek.

Movement of Radionuclides in Creek Water

The amounts of Sr^{90} detected at the temporary stream-sampling
stations appears to vary with stream discharges (see Fig. 6). Also,
an increase in the load of suspended solids in the streams is
generally followed by a corresponding increase in cesium transport
(see Fig. 7). Thus, during periods of high stream discharge and/or
a heavy suspended solid load, the transport of strontium and/or
cesium is unusually high.

A sampling train that separates suspended solids directly from
creek water was used to study the transport of suspended solids
and their associated activity in White Oak Creek. The unit,
developed by Dorr-Oliver, Incorporated specifically to classify
the solids in the ORNL low-level waste stream, consists of a Merco
Bantam Strainer and four separate hydrochlones. The median diameters
of the solids removed from the hydroclones are 29 µ, 19 µ, 12 µ,
and 9 µ.

To date eight operating runs, ranging from 1-hr to 4-hr
duration, have been made in White Oak Creek at WOCM 1.8. The
flow in the creek for the sampling periods varied from 5 cfs
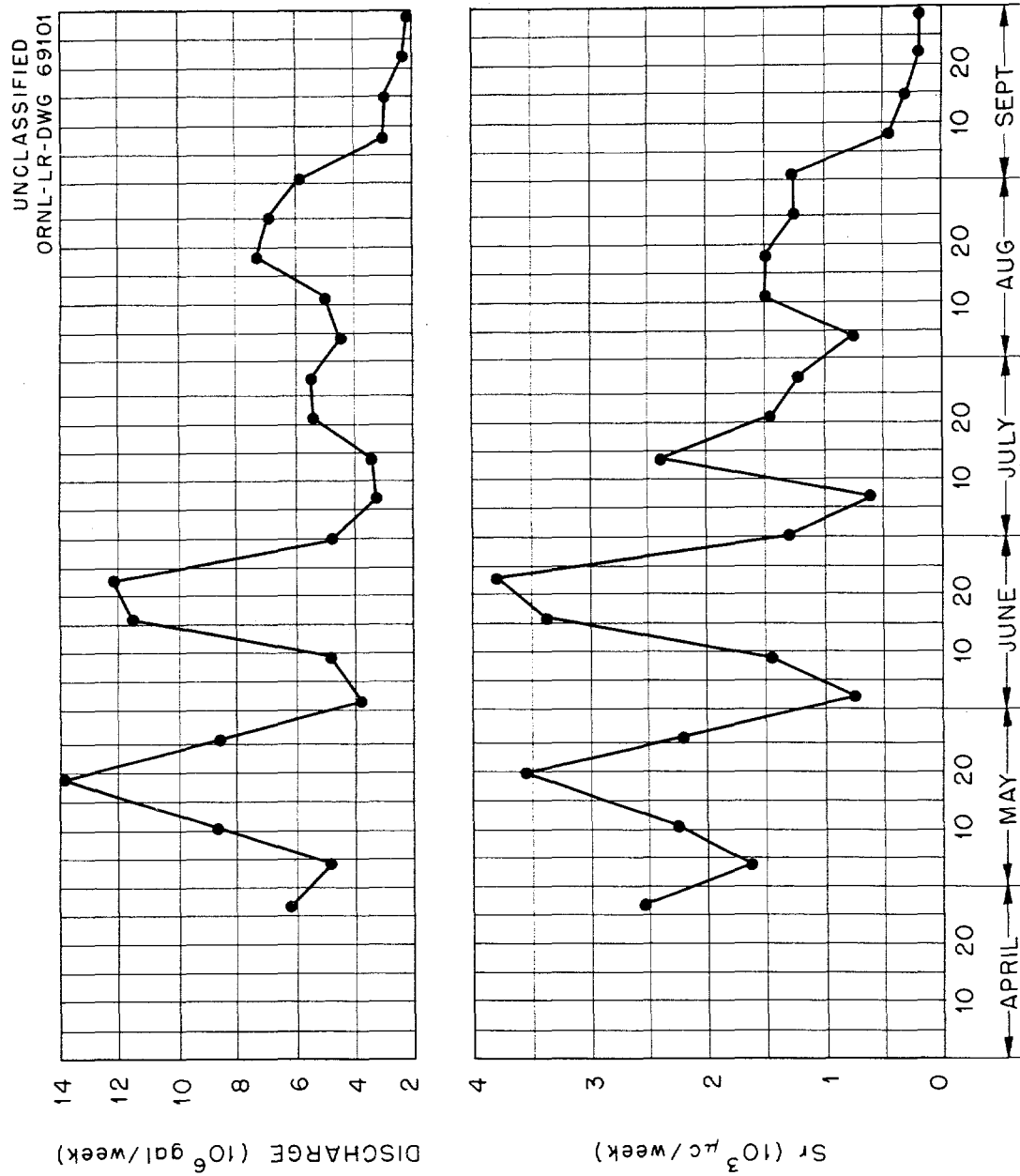
Fig. 6. Stream Discharge and Sr Transport at Northwest Tributary Station.
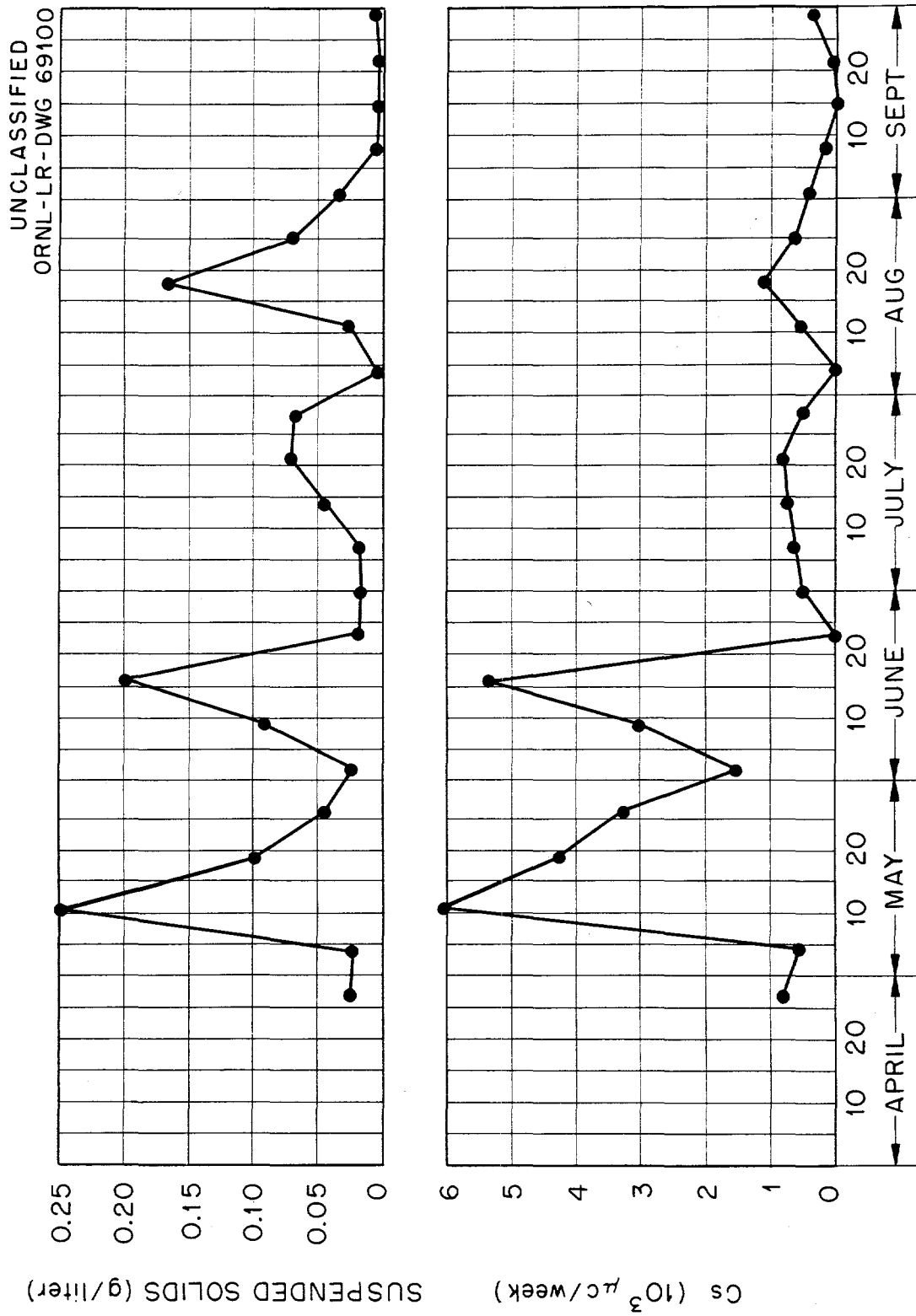
Fig. 7. Suspended Solids Concentrations and Cs Transport at Northwest Tributary Station.

(one half the average of 10 cfs) to 57 cfs, and the concentration of suspended solids in the water varied from 0.004 g per liter to 3.26 g per liter. Construction work in and around the creek, which has resulted in the removal of soil cover, may account in part for the extremely high concentrations of suspended solids in some of the runs.

A summary of the percentages of cesium and strontium in creek water associated with the liquid phase[*] and with several particle-size ranges of suspended solids for the eight runs is presented in Tables 2 and 3. The highest values of sorbed cesium and strontium occurred in runs 2, 7, and 8, which were the runs made during high suspended-solids load and high stream flow. The maximum of sorbed strontium was approximately 25% (run 7), while as much as 96% of the cesium in the creek water was found to be associated with suspended solids in runs 7 and 8. This suggests that during low flow rates and/or low suspended solids loads most of the strontium and cesium in White Oak Creek is associated with the liquid phase, but during high stream flows and/or heavy suspended-solids loads practically all of the cesium and a significant part of the strontium is transported downstream by suspended solids. Tables 2 and 3 also indicate that there was considerably more activity associated with suspended solids smaller than 9 μ in size

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[*]Liquid phases includes materials not retained by 0.45-micron Millipore filter.

Table 2. Percentages of Cs^{137} in Liquid and Solid Phase of White Oak Creek Water

Run Number	Flow in Creek (cfs)	Suspended Solid Concentrations (g/liter)	Liquid Phase (%)	Median Diameter Particle Size (%)					
				< 9 μ	9 μ	12 μ	19 μ	29 μ	> 250 μ
1	14.4	0.011	71.3	25.7	0.2	1.0	1.3	0.5	< 0.1
2	57.2	0.044	50.7	39.9	0.5	1.8	3.5	2.6	1.0
3	5.5	0.004	58.7	37.7	0.9	1.2	0.3	1.2	< 0.1
4	6.1	0.012	79.5	19.3	0.4	0.4	0.1	0.3	< 0.1
5	5.0	0.010	79.6	18.8	0.5	0.5	0.5	0.1	< 0.1
6	5.3	0.006	77.1	15.9	2.2	1.9	2.2	0.6	0.1
7	7.8	3.261	4.3	85.3	4.0	2.4	2.9	1.1	< 0.1
8	43.5	0.692	3.9	65.4	7.8	5.6	8.7	8.3	0.3

Table 3. Percentages of Sr^{90} in Liquid and Solid Phase of White Oak Creek Water

Run Number	Flow in Creek (cfs)	Suspended Solid Concentrations (g/liter)	Liquid Phase (%)	Median Diameter Particle Size (%)					
				< 9 μ	9 μ	12 μ	19 μ	29 μ	> 250 μ
1	14.4	0.011	99.26	0.61	0.03	0.03	0.04	0.03	< 0.01
2	57.2	0.044	98.09	1.01	0.08	0.17	0.47	0.17	0.01
3	5.5	0.004	99.30	0.55	0.04	0.06	0.01	0.04	< 0.01
4	6.1	0.012	99.63	0.33	0.02	0.01	< 0.01	0.01	< 0.01
5	5.0	0.010	99.43	0.52	0.02	0.02	0.01	< 0.01	< 0.01
6	5.3	0.006	99.50	0.40	0.04	0.03	0.02	0.01	< 0.01
7	7.8	3.261	75.52	18.07	3.36	1.68	1.10	0.27	< 0.01
8	43.5	0.692	92.92	3.94	0.87	0.69	1.06	0.50	0.02

than with the larger particle sizes. For suspended solids greater than
9 μ, considerable variation was found in the amounts of activity
associated with the various separated fractions within each test run
and between test runs. It may be noted that, in general, the maximum
concentrations of activity were not found in any particular particle-
size group for all the tests.

Summary and Conclusions

Approximately 65% of the strontium-90 and 50% of the cesium-137
in White Oak Creek is due to release from the PWWTP, while seepage
from the waste pits accounts for practically all of the ruthenium-106
and cobalt-60 in the system.

During periods of high stream flow and/or suspended solids load
in White Oak Creek, there are substantial increases in the quantities
of cesium and strontium transported downstream. The exact source
of the additional activity is not known. It is likely that much of
the increase is due to scouring in the stream bed; however, some
may be due to surface runoff from contaminated soils and ground-
water leaching of buried sources.

The amount of activity transported downstream by suspended solids
is relatively small during low creek-flow rates and/or low suspended-
solids loads, but during high stream flows and/or high suspended-
solids loads, significant quantities of strontium, and practically
all of the cesium, is associated with suspended sediments.

Several thousand curies per year of ruthenium flow onto the
bed of former White Oak Lake from the waste pits, but less than
half of this material finds its way into White Oak Creek.

During the dry summer months the streams that drain the waste pit area recharge the ground water in the lake bed. Therefore, only a small amount of waste solution containing ruthenium travels over the land surface to the creek. However in the wet winter months more of the waste water flows over the surface of the lake bed and as a consequence larger amounts of ruthenium enter the creek.

BIOLOGICAL PHASES

Biological investigations pertinent to the Clinch River study are conducted by several participating agencies with active leadership from the Ecology Section of the ORNL Health Physics Division. The other participants are the U. S. Public Health Service, Tennessee Valley Authority, and Tennessee Fish and Game Commission. The Subcommittee on Aquatic Biology, composed of representatives of ORNL, USPHS, TVA, and TFGC, is responsible for guidance of the ecological and biological phases of the Clinch River study. This includes planning, coordination, interpretation, and reporting of results. Each of the participating agencies mentioned above is engaged in its own programs of broader scope than the present Clinch River study, but within these programs data can be collected and reported in such a way as to be useful to the steering committee and particularly to the Subcommittee on Safety Evaluation.

The Subcommittee on Aquatic Biology has developed statements of the objectives and scope of biological studies relevant to the Clinch River study, the areas of investigations and surveys necessary to achieve the objectives, and an outline of specific studies currently in progress and the agencies involved.[9] Since certain phases of this study require work on the Tennessee River as well as more intensive work on the Clinch River, the statement of scope and outline of studies refer generally to both the Clinch River and the Tennessee River systems. These statements of the subcommittee and interim reports on four specific studies are summarized below.

Purpose and Scope of Investigations

The objectives of the biological phases of the Clinch River study
are to: (1) develop information on the extent to which radioactive
contamination of the river biota may be an immediate and/or long-term
hazard to human populations, (2) develop data which will provide a
basis for estimating the capacity of the river for continuous input
of radioactive wastes, and (3) evaluate the possible long-term effect
of ionizing radiation on the biotic communities in this environment.

Areas of investigations and surveys to achieve these objectives
include:

1.0 Biological Relationships.- Studies on the kinds, quantity,
movement, and turnover of biomass in the Clinch River.

2.0 Radionuclide Accumulation.- Determination of radionuclide
content in the Clinch River biomass as related to location, position
in the ecological food chain, season, and use as human food.

3.0 Chemical Relationships.- Investigation of the rates of
uptake and turnover of radionuclides by fish and other biota in
relation to chemical and other environmental factors.

4.0 Radiation Effects.- Investigations concerning the effects of
chronic, low-level radiation on selected river populations.

Biological Relationships

Flora and Fauna of the River Community--Melton Hill Preimpoundment Studies

An investigation of fishery and other ecological conditions in the
Clinch River area to be impounded by Melton Hill Dam was initiated in
1960. Purposes are to determine: (1) the existing composition and
abundance of river fishes for possible management recommendations

prior to and immediately following impoundment; (2) the present quality and value of fishing and associated recreation for comparison with future lake values; (3) the seasonal movement of various fishes, such as sauger and white bass as well as rough fishes, from Watts Bar Reservoir upstream into the Melton Hill Area; and (4) the quality of the water for possible extended trout habitat downstream from Norris Dam tailwater. Preliminary data will also be collected for use in determining the effects of the Bull Run Steam Plant to be erected within the Melton Hill Reservoir area.

Melton Hill Dam is located at CRM 23.1 near the head of Watts Bar Reservoir. At maximum pool level of 795 feet M.S.L., this project will back water upstream 44 miles (8 miles above Clinton), will provide one lock 75 by 400 ft at the dam and a 9-ft navigation channel extending upstream to the Eagle Bend area above Clinton, and will have 140 miles of shore line and a water-surface area of 5,720 acres. Inflow will be regulated almost completely by Norris Dam 57 miles upstream. Melton Hill Dam is scheduled for completion in the spring or early summer of 1963.

During the period July 1960 to June 1961 preliminary information was obtained from two rotenone samples of fish in the main river and a few in tributary pools and from seasonal gill- and hoop-net collections at regular established stations. An interim report giving details of the methods and conditions of these collections was submitted to the steering committee.[9] A summary of data from the net collections at four stations is given in Table 4. Selected excerpts from the interim report are mentioned below.

Table 4. Summary of Net Collection Data from Four Stations in the Melton Hill Reservoir Area of Clinch River, 1960-61.

| | Total Fish Collected | | | | Ave. per Net/Day | | |
| | Game Fish | | Rough Fish | | | | |
Dates	No.	Wt (lb)	No.	Wt (lb)	Net Days	No.	Wt (lb)
ABOVE MELTON HILL DAM SITE, CRM 23-24							
Nov. 14-15, 1960	2	1.3	272	283.4	7	39.2	40.7
Feb. 9-10, 1961	1	1.2	6	4.9	8	0.9	0.8
June 22-23, 1961	4	2.5	120	202.0	8	15.5	25.3
Total	7	5.0	398	490.3	23	17.6	21.5
NEAR EGCR REACTOR SITE, CRM 33-34							
Nov. 9-11, 1960	5	5.9	81	136.9	14	6.2	10.2
Feb. 9-10, 1961	1	1.6	13	21.0	8	1.7	2.6
June 22-23, 1961	1	1.4	47	83.0	8	6.0	10.6
Total	7	8.9	141	240.9	30	4.9	8.3
EDGEMOOR BRIDGE, CRM 47-48							
Nov. 7-9, 1960	4	6.0	174	264.6	12	14.8	22.5
Jan. 6-7, 1961	2	2.6	68	108.4	7	10.0	15.9
June 22-23, 1961	6	2.7	46	88.9	8	6.5	11.5
Total	12	11.3	288	461.9	27	11.1	20.5
BELOW HIGHWAY 61 BRIDGE, CRM 66							
Feb. 10-11, 1961	1	0.5	7	3.8	5	1.6	0.9
June 22-23, 1961	23	11.1	114	173.9	8	17.1	23.1
Total	24	11.6	121	177.7	13	11.3	14.6
Grand Totals	50	36.8	948	1,370.8	93	10.7	15.1

Rough fishes have dominated the net catches at all stations, which is not considered unusual. Of the grand total of nearly 1,000 fish weighing over 1,400 pounds netted during the period, only 5% of the number and 2.5% of the weight were game fish. Game species included sauger, white bass, white crappie, spotted bass, bluegill, rock bass, warmouth, and rainbow trout. Twenty-one species of rough fish were netted in these preimpoundment collections. At least 12 of these species have some commercial value and it can be expected that Melton Hill Reservoir will support sizeable commercial fishery operations.

Considerable seasonable movement of various species from Watts Bar Reservoir may be expected after impoundment. Of the game fishes, sauger, white bass, and crappie will move into the area below the dam and through the locks. Various suckers and other rough species will migrate to the headwaters in spring.

Human Use of Aquatic Natural Resources--Harvest by Commercial Fishermen

Estimates of commercial fish harvested from Watts Bar Reservoir during the four-year period 1958-1961 are summarized in Table 5. Of the categories listed, quillback, buffalo, and carp are shipped to northern market centers (New York, Chicago, and St. Louis) where they are used strictly for human consumption. Paddlefish and catfish are sold locally within the state of Tennessee, also for human food.

The data in Table 5 provided some idea of the magnitude of the current commercial fishery business on Watts Bar Reservoir.

Table 5. Commercial Fish Harvest--Watts Bar Reservoir--1958-61

| Year | Weight by Species (lb) | | | | | | | | | Total Wholesale | |
	Paddlefish	Catfish	Drum	Quillback	Buffalo	Carp	Sturgeon	Gar	Turtles	Weight (lb)	Value ($)
1958	12,175	54,333	3,935	8,240	15,687	8,058	-	-	-	102,430	$20,931.18
1959	27,450	83,065	5,995	53,990	54,035	20,595	15	-	-	245,145	39,771.70
1960	25,430	66,080	5,460	30,660	63,705	22,170	-	-	-	213,505	33,971.10
1961	38,910	50,367	1,476	17,068	59,328	13,149	-	-	232	180,530	24,900.31

In so far as is known these fish are used only for human food. Inasmuch as a reduction in the abundance of such species is considered sound practice in modern fish management, it is anticipated that the harvest of these fish will be encouraged and will increase.

Chemical Relationships

Chemical (Stable) Analyses of Organisms--Strontium in White Crappie Flesh and Bone

When the distribution of Sr (stable) between fish and water is known, it should be possible to predict the levels of Sr^{90} to be found in fish living in water receiving a constant release of Sr^{90} Therefore, the relationship

$$\frac{Sr \text{ in fish tissue}}{Sr \text{ in water}} = \frac{Sr^{90} \text{ in fish tissue}}{Sr^{90} \text{ in water}} \text{ or,}$$

$$Sr^{90} \text{ in fish tissue} = \frac{Sr \text{ in fish tissue} \times Sr^{90} \text{ in water}}{Sr \text{ in water}}$$

may be used to calculate the expected burden for a constant release of Sr^{90}. The flesh and bone of white crappies are being analyzed for Sr in order to make these predictions.

The concentration of Sr in flesh of 9 white crappies were: 6.6, 10.3, 8.6, 9.6, 5.4, 4.6, 6.8, 6.4, and 6.5×10^{-8} grams Sr per gram of flesh, wet weight (average 6.6×10^{-8} g Sr/g flesh). Strontium concentrations in Clinch River water averaged 5.9×10^{-8} grams Sr per gram of water (Status Report No. 2 on Clinch River Study[10]). For convenience, the expected body burden of Sr^{90} in fish may be calculated by using the above data on Sr

in fish and water and assuming a Sr^{90} concentration in water equal
to the MPC_w for continuous occupational exposure, i.e., 1 μμc Sr^{90}/cc
water. The body burden calculated on this basis is 1.12 μμc Sr^{90}/g
flesh (1120 μμc/kg). When the Sr^{90} determinations are completed on
these fish, the actual body burden may be expressed as a fraction of the
expected body burden at MPC_w.

The Sr and Sr^{90} concentrations in the same samples of white-crappie
bone have been determined (Table 6) and it is possible to compare the
theoretical Sr^{90} concentrations in bone with those values observed by
analysis. The calculated or theoretical Sr^{90} burden in fish bone was
3.85 x 10^3 μμc Sr^{90}/g bone, dry weight, based on the MPC_w for continuous
occupational exposure. The average Sr^{90} burden determined by analysis
was 1.20 x 10^2 μμc Sr^{90} g/bone, dry weight, which was 3.1 per cent of
the theoretical activity. Laboratory releases of Sr^{90} vary from 10 to
30 per cent of the MPC values for water in the neighborhood of nuclear
energy installations which in turn are 10 per cent of the occupational
values. Therefore, these preliminary observations on bone are in
good agreement with the expected bone concentrations.

The hazard to humans from the consumption of Clinch River fish
may be estimated from the theoretical burden in fish. The human body
burden of Sr^{90} resulting from the consumption of white crappie was
calculated on the following assumptions and criteria:

1. The Sr^{90} concentration in fish flesh is 1.12 μμc/g
   (based on the expected concentration in fish living
   in water which continuously receives releases of Sr^{90}
   equal to the MPC for continuous occupational exposures).

Table 6. Results of Analyses for Sr and Sr^{90} in White Crappie Bone

	Sr (μg/g bone)	Sr^{90} (μμc/g bone)
	217	36.7
	250	24.5
	218	10.0
	204	277.0
	189	12.6
	234	295.0
	251	3.0
	230	9.4
	244	297.0
	233	232.0
Average	227	120.0

Table 7. Distribution of Cs^{134} in Bluegill Tissues

Tissue	Cs^{134}(μμc x 10^{-3}/g dry wt.)
Scale	146
Skin	726
Muscle	415
Liver and digestive tract	849
Ovary	1285
Gills	663
Bone	11
Fins	151

2. One-half pound of fish is eaten each week (average of 32.4 g/day).

3. Data pertaining to Sr^{90} are from the Report of Committee II ICRP.[11]

   a. Bone is the critical organ.

   b. The effective half-life of Sr^{90} in bone is 6.4×10^3 days.

   c. Of the ingested Sr^{90} 9 per cent is deposited in bone.

   d. Sr^{90} reaches 86 per cent of its equliibrium value in humans in 50 years.

   e. The maximum permissible body burden in bone for occupational exposure is 2 μc.

4. The calculation of the equilibrium value (qf_2) is based on the exponential model for critical organs other than the GI tract.

$$qf_2 = P \ (1-e^{-\lambda t})/\lambda$$

in which

P is the rate of ingestion of Sr^{90} in μc/day.

For long periods of time $1-e^{-\lambda t}$ becomes one.

λ is the effective decay constant $0.693/T$, where T is the effective half-life of Sr^{90} in bone.

Therefore, $qf_2 = \dfrac{32.4 \times 1.12 \times 10^{-6} \times 0.09}{0.693/6.4 \times 10^3}$

$= \dfrac{3.26 \times 10^{-6}}{0.108 \times 10^{-3}}$

$= 3.02 \times 10^{-2}$ μc

Under the above assumptions and criteria, the 50-year burden is 86 per cent of this which is 2.6×10^{-2} µc Sr^{90} or 1.3 per cent of the occupational burden. This would be 13 per cent of the permissible burden for individuals living in the neighborhood of nuclear energy installations. The permissible body burden for the population at large is 1/30 of that for occupational exposure or 6.67×10^{-2} µc. A member of the population at large eating white crappies in the manner stated would accumulate 39 per cent of his maximum permissible body burden. It must be appreciated that the above assumptions maximize the potential exposure from this source; and that the eating of smaller quantities or less contaminated fish, even part of the time, would reduce the estimated exposure.

Uptake and Elimination of Radionuclides in Organisms--Biological Half-Life of Cs^{134} in Bluegills

The biological half-life of fission-product elements in fish is being determined because this parameter has a direct bearing on the dispersal of radionuclides by fish as they move from contaminated to uncontaminated areas of the river. The initial experiments are with bluegills (Lepomis macrochirus), a common panfish.

Fish are fed contaminated worms to build up a body burden of Cs^{134}. They are then placed in aquaria through which uncontaminated water circulates and with uncontaminated worms used for further feeding. These fish are counted periodically with gamma scintillation equipment, and the decrease in radioactivity is a measure of the excretion of Cs from the tissues.

The experiments are still in progress but data from the first 3 fish (Figure 8) suggests a biological half-life of about 40 days for Cs^{134}. Bluegill "A" was accidentally killed. This fish was dissected and the individual body components were counted (Table 7, p. 41). Concentrations of Cs^{134} were highest in the soft tissues such as ovary, digestive tract, and skin and lowest in hard tissues (bone, scales, and fins). Additional fish will be studied to determine whether the distribution of Cs^{134} is similar in the individual tissues.
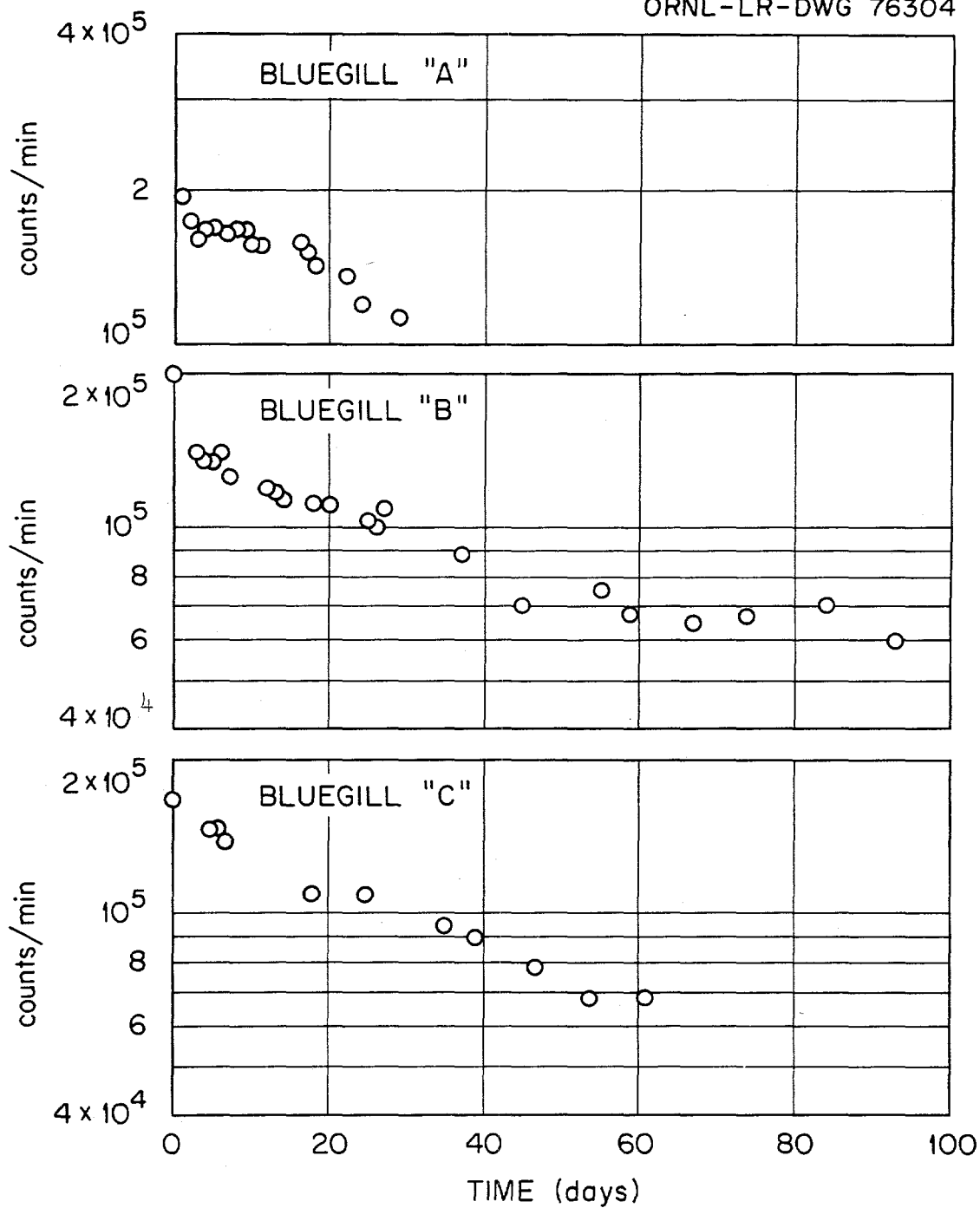
Fig. 8.   Decrease of Cs^{134} Activity in Bluegills with Time.

HYDROLOGIC MEASUREMENTS AND ANALYSES

The U. S. Geological Survey has continued its cooperative
program of routine measurements and special observations relative
to surface water hydrology in the Oak Ridge area. Many of the
measurements are made and the data furnished as requested for specific
use in the Clinch River study. Other parts of the program are to
provide basic information and over-all appraisal of the hydrology of
the area for various purposes, but they prove highly useful in the
analysis of transport of radionuclides by streams and in the
interpretation of analytical results in the Clinch River study.

In addition to the aforementioned activities data have been
collected on the Clinch River for specific studies, such as time of
water travel, sediment transport, velocity and temperature profiles,
effects of power waves, dilution factors, and dispersion of materials
in the river system. Programmatic cooperation by the USGS and four
special studies by joint efforts of the USGS and the Laboratory are
summarized below.

Summary of the USGS Program

The operation of a network of eight stream-gaging stations
on the Clinch River and tributary streams in and immediately
adjacent to the ORNL area has been continued. The information
collected at these sites varies somewhat but generally includes
a continuous record of stage, discharge, and temperature as shown
in Table 8. Also included in Table 8 is a temperature recording
station at CRM 5.5 operated by ORNL and USGS personnel of the Clinch River
Study to obtain data on water temperatures at several depths in the river.

Table 8. Basic Network of Gaging Stations Operated and Data Provided by USGS[12]

Station Number	Station Name	Records Available	Data Provided (Continuous)		
			Stage	Discharge	Temperature[a]
3-5355	Clinch River near Scarboro	1941-	x	x	
3-5370	White Oak Creek below ORNL near Oak Ridge	1950-53 1955-	x	x	
3-5375	Melton Branch near Oak Ridge	1955	x	x	
3-5380	White Oak Creek at White Oak Dam near Oak Ridge	1953-55 1960-	x	x	
3-5382.75	Bear Creek near Oak Ridge	1960-	x	x	x
3-5382.5	East Fork Poplar Creek near Oak Ridge	1960-	x	x	x
3-5382.25	Poplar Creek near Oak Ridge	1960-	x	x	x
	Clinch River at CRM 19.1 near Oak Ridge	1960-	x		x
	Clinch River above Centers Ferry at CRM 5.5	1961-			x[b]

[a]Temperature data available for only part of the 1961 water year.

[b]Station installed and operated by ORNL and USGS personnel for determining and recording water temperatures at various depths.

In addition to the 8-station stream-gaging network an auxiliary network of 24 partial-record stations provides background data for flood frequency and low-flow analyses. Water samples are collected at all sites in order to provide background data on sediment transport and chemical quality.

During the six-month period since the last progress report to the steering committee the USGS has:

1. Provided provisional mean daily gage heights and discharges (vital to waste-disposal operations at ORNL) to the Radioactive Waste Disposal Research Section of the Health Physics Division on a monthly basis for Clinch River near Scarboro, White Oak Creek below ORNL, White Oak Creek at White Oak Dam, Melton Branch, and the ORNL Settling Basin effluent.

2. Published 1961 water year records in the basic-data release for Tennessee.[12] This report includes stream flow and other hydrologic data from the regular gaging stations and the partial-record gaging-station network.

3. Furnished weekly discharges to the chairman of the Subcommittee on Water Sampling and Analysis for the period August 6, 1961 to February 3, 1962 for White Oak Dam, Clinch River at Scarboro, and Clinch River at Centers Ferry; and also monthly discharges during the same period for the Tennessee River at Loudon.

4. Run a dispersion test on the Clinch River February 1, 1962 as reported below (see page 61).

5. Collected sediment samples and velocity data for a reach of the Clinch River below White Oak Creek on March 15, 1962 during a period of steady release of 18,000 cfs from Norris reservoir.

These data were furnished to the chairman of the Subcommittee on Bottom Sediment Sampling and Analysis.

6. Made a round of medium base-flow measurements and collected water samples for determination of major and minor chemical constituents at all partial-record stations on September 18-19, 1961. The results of the analyses when completed can be furnished to members of the steering committee.

7. Obtained high water measurements at regular and partial-record gaging stations during the floods of December 1961 and February 1962.

8. Provided assistance on special problems as requested.

Plans for the future program of the USGS in support of the Clinch River study include continued operation of the regular and partial-record gaging-station networks and provision of assistance and data on specific problems as requested. As an addition to the program the USGS plans to:

1. Install tipping-bucket rain gages at the gaging stations on White Oak Creek below ORNL, Melton Branch, Bear Creek, and East Fork of Poplar Creek in order to study the lag time between centers of mass of precipitation and runoff.*

2. Determine the practicability of using the reach of Clinch River from Melton Hill Dam to CRM 19.1 in a slope-discharge relationship in order to determine discharges on the Clinch River from the time the Scarboro gaging station is inundated by backwater from Melton Hill Dam until flow records based on turbine releases become routinely available.*

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*Subsequent to April 25, 1962, Item "1" was completed, and Item "2" is in progress.

Studies of Time of Travel in White Oak Creek

In order to add to the knowledge of time required for water and possible associated contaminants to travel from the ORNL area to the uncontrolled environment, 3 time-of-travel studies were made in White Oak Creek in 1962.

The first study, made May 1-3, 1962, consisted simply of introducing fluorescein dye into the stream at the Laboratory and, following its travel visually, noting its time of arrival at landmarks near the channel. This method measured minimum time of travel only. The general results of this study are shown in column 1 of Table 9.

The second study, made on May 16, 1962, was done using Gold-198 as the tracer which was introduced into the stream at Haw Ridge water gap. The passage of the tracer at various points was observed with submerged scintillation detectors. The success of this study was limited by the high radiation background reading and by the failure of two of the instruments. Consequently, passage of the tracer was measured only below the old intermediate pond and at the gaging station "White Oak Creek below ORNL." General results of this study are shown in column 2 of Table 9.

The third study, made on October 31, 1962, was again done with fluorescein, introduced into the stream at the Laboratory. Samples were collected at several stations at 5-minute intervals during passage of the dyed water and later measured for fluorescence. General results of the study are shown in column 3 of Table 9.

Because of the complex water temperature-density relationships in White Oak Creek the second and third studies failed to follow the travel of the tracer to White Oak dam. Results of the first study, however,

Table 9. Summary of Results of Time-of-Travel
Studies in White Oak Creek, 1962

| Column Number | (1) | (2) | (3) |
Date of Study	May 1-3[a]	May 16[b]	October 31[c]
Discharge at gaging station "White Oak Creek below ORNL" (cfs)	5.5	4.7	4.5
Length of channel studied (ft)	10,185	3,650	10,185
Mean velocity (ft/sec)	not known	0.45	0.56
Maximum velocity (ft/sec)	0.62	0.72	0.67
Velocity of peak concentration (ft/sec)	not known	0.50	0.58
Minimum time of travel (hr:min)	4:35	1:33	5:30
Mean time of travel (hr:min)	not known	2:11	6:20

Notes (see column numbers).

[a]Study made May 1-3, from Building 4500 to old boat-dock bridge.

[b]Study made May 16, from Haw Ridge water gap to gaging station White Oak Creek below ORNL

[c]Study made October 31, from Building 4500 to old boat-dock bridge.

showed that under the conditions that prevailed at that time, about
2 hours were required for travel from the old boat-dock bridge to
White Oak Dam. The results shown for the first study (column 1) were
computed for the channel from building 4500 to the boat-dock bridge
for comparison to later tests, and do not include the travel time through
White Oak Lake.

The times of travel shown in Table 9 are representative of base-flow conditions for the lengths of channel studied. Future tests will be made to characterize time of travel in White Oak Creek throughout the range of flow conditions.

Estimated Effects of Power Releases from Melton Hill Reservoir on Water Levels in White Oak Lake

In the first quarter of 1964 generation of hydroelectric power is scheduled to begin at Melton Hill Dam. The release of water used in the generation of power will cause daily variations in the water level of Clinch River. As a result, immediately downstream from White Oak Dam the backwater from Clinch River will normally produce a daily rise in water level from El. 740.0 ft to El. 744.5 ft between late spring and early fall, and from El. 735.0 ft to El. 742.7 ft in winter for a maximum release of 23,000 cfs through the hydroelectric turbines.[13]

As a consequence of the increase of backwater above normal pool levels of Watts Bar Reservoir at White Oak Dam some increase in the area of White Oak Lake will occur. The crest of the lower gate in White Oak Dam is presently set at El. 741.3 ft. The increase in area will depend on the water level and duration of backwater from Clinch River, the elevation of the slide gate in White Oak Dam, and the inflow from White Oak Creek to the lake.

As a basis for project planning for the Melton Hill Project three possible patterns of weekly power release operations during the winter months have been described and shown in a figure by the Tennessee Valley Authority.[14] These patterns, adapted as shown in Fig. 9, have been used as a guide to indicate the duration of the high backwater at the

53

NOTE: THE AVERAGE WEEKLY INFLOWS OF 2900, 6000, AND 8000 cfs ARE
THOSE EXPECTED TO BE EQUALED OR EXCEEDED ABOUT 90%, 50%
AND 30% OF THE TIME, RESPECTIVELY DURING THE WINTER MONTHS.
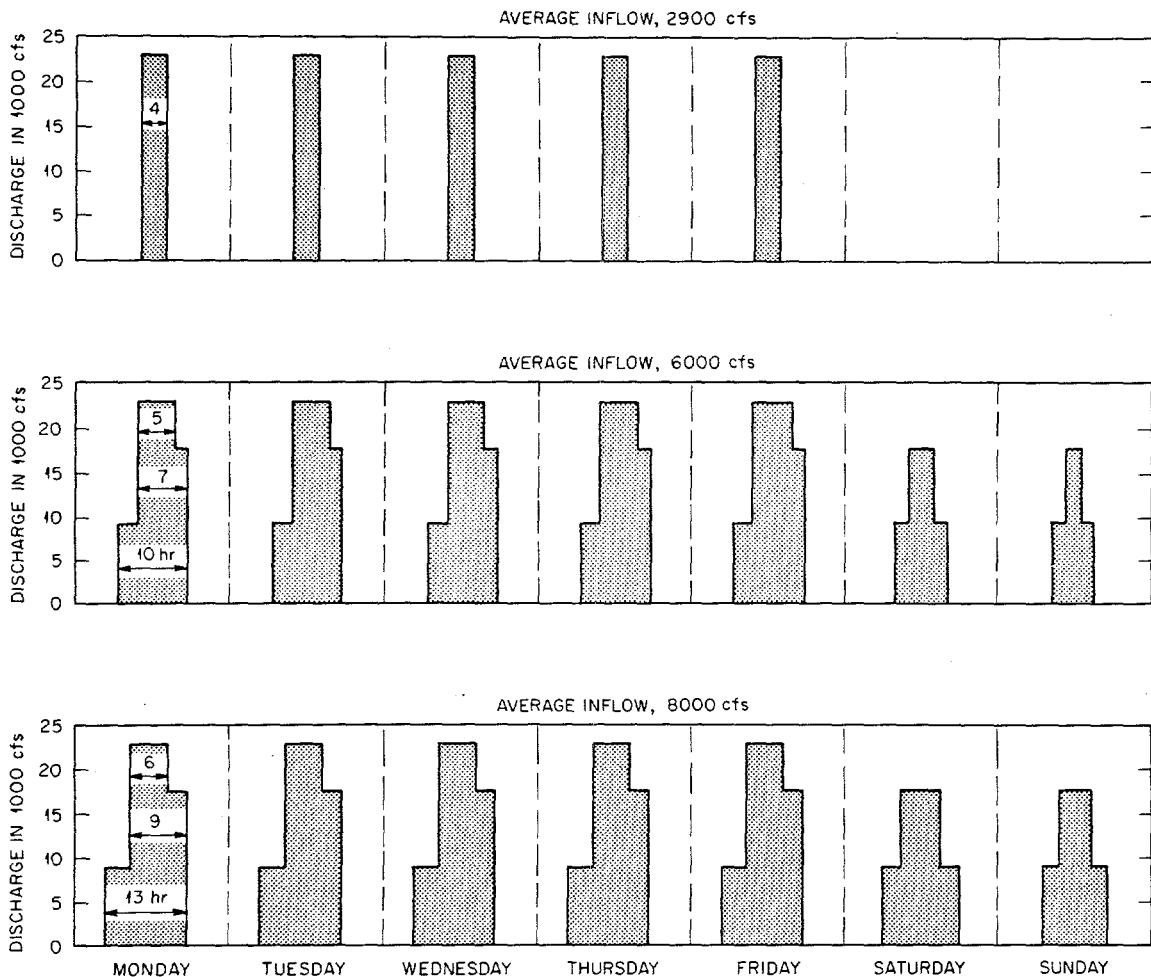
Possible Schedule of Releases from Melton Hill Reservoir for Various Average Weekly Inflows to the
Reservoir. (Adapted from "The Melton Hill Project", Report No. 36-100-1, Proj. Planning Branch, Div. of
Water Control Planning, TVA, Sept. 1957)

Fig. 9. Possible Schedule of Releases from Melton Hill Reservoir for
Various Average Weekly Inflows to the Reservoir During Winter Months.[14]

downstream side of White Oak Dam. In the similar figure in the report
by TVA the variation of electric power instead of discharge is shown.
It has been assumed that discharge is directly proportional to power
production in order to prepare Fig. 9. It will be noted that the
maximum backwater due to releases of 23,000 cfs may occur frequently
each week of winter, with a duration of from 4 to 6 hours. The maximum
duration of the water-level rise due to power releases may be about 12
to 13 hours.

For the purpose of estimating an extreme condition of increased
surface area in White Oak Lake, it has been assumed that the maximum
release occurring between the late spring and early fall may approach
the maximum winter release--23,000 cfs. The maximum backwater level
for these assumptions is El. 744.5 ft.

Three possible positions of the slide gate which controls
the flow from White Oak Lake have been considered (cases 1, 2, and 3
below; see Figure 10):

1. The gate is set permanently at El. 745.0, 0.5 ft above
maximum backwater.

2. For a period of 12 hours, a possible duration of power
releases from Melton Hill Reservoir, the slide gate is closed;
after the backwater has receded to the normal pool level of Watts Bar
Reservoir, the gate is returned to El. 741.3 ft.

3. The gate is set permanently at its present level, El. 741.3
ft.

For all computations the inflow from White Oak Creek to the
lake has been assumed to be 10 cfs.

CASE 1:
SLIDE GATE SET AT EL. 745.0 ft, 0.5 ft ABOVE MAXIMUM
BACKWATER LEVEL FROM CLINCH RIVER. FOR A FLOW OF
10 cfs OVER THE GATE THE RESULTANT LAKE LEVEL IS
EL. 745.85 ft.

WHITE OAK DAM
LAKE EL. 745.85
CLINCH RIVER EL. 744.5
GATE SET AT EL. 745.0
CLINCH RIVER

CASE 2:
FOR A PERIOD OF 12 HOURS, A POSSIBLE DURATION OF POWER RELEASES
FROM MELTON HILL RESERVOIR, THE SLIDE GATE IS RAISED FROM
EL. 741.3 ft TO EL. 745.0 ft; FOR THE HIGHER GATE SETTING NO FLOW
OVER THE GATE WILL OCCUR. FOR AN INFLOW OF 10 cfs FROM WHITE OAK
CREEK THE LAKE LEVEL WILL BE RAISED FROM EL. 742.15 ft TO 743.0 ft
DURING THE PERIOD OF CLOSURE.

GATE SET AT EL. 745.0 ft
MAX. LAKE LEVEL, EL. 742.15 ft
OFF PEAK LAKE LEVEL, EL. 742.15 ft
GATE SET AT EL. 741.0
WHITE OAK DAM
MAX. LEVEL
CLINCH RIVER EL. 744.5
OFF PEAK, SUMMER LEVEL
CLINCH RIVER EL. 741.0
CLINCH RIVER

CASE 3:
SLIDE GATE IS SET AT EL. 741.3 ft, PRESENT OPERATING LEVEL.
FOR A MAXIMUM RELEASE FROM MELTON HILL RESERVOIR THE
LEVEL OF CLINCH RIVER WILL RISE TO EL. 744.5 ft. ASSUMING THE
RIVER REMAINS AT THIS LEVEL FOR 6 HOURS AND AN INFLOW OF
10 cfs FROM WHITE OAK CREEK THE LEVEL OF WHITE OAK LAKE
WILL RISE FROM EL. 741.8 ft TO EL. 744.3+ ft.

WHITE OAK DAM
CLINCH RIVER EL. 744.5
FINAL LAKE LEVEL, EL. 744.3+
ORIG. LAKE LEVEL, EL. 742.15
GATE SET AT EL. 741.3
WHITE OAK CREEK
CLINCH RIVER

ECOLOGY STUDY AREA

746
744
742
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744
742
744
746

POSSIBLE
LAKE BOUNDARIES
CASE 1
CASE 2
CASE 3
PRESENT BOUNDARY OF LAKE

SPILLWAY

WHITE WING
ROAD

Fig. 10. Possible Limits of Inundation in White Oak Lake.

In case 1 the outflow from the lake at White Oak Dam will be nearly in equilibrium with the inflow to White Oak Lake upstream from the dam. From the discharge rating for White Oak Creek at White Oak Dam, prepared by the USGS, the lake level rises 0.85 ft above the crest of the present gate setting (El. 741.3 ft) for an outflow of 10 cfs. Assuming that the discharge rating will apply similarly to a higher gate setting of El. 745.0, the lake level will reach El. 745.85 for the assumed inflow and outflow of 10 cfs.

In case 2 the increase in lake level is due only to inflow to the lake upstream from the dam. For an inflow of 10 cfs for 12 hours the volume stored in the lake will increase 432,000 cu ft. From area-capacity curves and tables in a memorandum report by A. S. Fry[15] the rise in lake level due to this additional storage has been computed to be about 0.9 feet, 1.7 feet above the level of the present gate setting. Work by T. F. Lomenick[16] has indicated that the capacity table, dated June 1953, (see Table 10) prepared by Fry will approximate capacity conditions in 1960.

In case 3 the lake level will increase because of inflows from White Oak Creek upstream from the dam and from Clinch River backwaters through the dam. The inflow from the creek is assumed to be 10 cfs. The backwater level downstream from White Oak Dam is assumed to be constant at El. 744.5 for six hours. The inflow due to backwater will continuously decrease because the water-level difference between the backwater and lake level is decreasing.

The change of lake level with time has been computed by combining the continuity equation, $I-O = \frac{ds}{dt}$, an approximation of the relation between volume and lake level (values listed in Table 10)

Table 10.   Capacity of White Oak Lake in June 1953[15]

Water Elevation (ft)	Water Volume (ft^3)
750	9,496,010
749	7,675,949
748	6,049,587
747	4,611,108
746	3,334,558
745	2,249,135
744	1,438,741
743	814,047
742	341,784
741	82,588
740	1,959
739	0

$$s = 8.26 (10^4) h_2^{2*}$$

in which

I = inflow in cfs

O = outflow in cfs

S = volume in ft^3

t = time in seconds

h_2 = rise in lake level, above El. 740 ft, in ft

and an approximate discharge relation for the inflows to White Oak Lake

$$I = 10 + 12.6 \left[\Delta h \right]^{3/2(1-n)} \left[h_1 - h_2 \right]^{3n/2}$$

in which

I = inflow in cfs

Δh = head on gate without submergence, 3.2 ft

$(h_1 - h_2)$ = difference in levels between backwater and the lake, in ft; $h_1 = 4.5$ ft

n = an exponent varying in value from 2/8 to 2/10.

The resulting differential equation,

$$t = \int_{2.1}^{\leq 4.5} \frac{16.5(10^4) h_2}{10 + 12.6 \left[3.2 \right]^{3/2(1-n)} \left[4.5 - h_2 \right]^{3n/2}} dh_2$$

was integrated numerically, using Simpson's rule.[17] Results of this integration are shown in Fig. 11. If n is 2/10 the lake level will rise to El. 744.4 ft in six hours. If n is 2/8 the lake level will rise to 744.3 ft in six hours.

*For a more precise estimate the factor $h_2^{2.06}$ might be used.
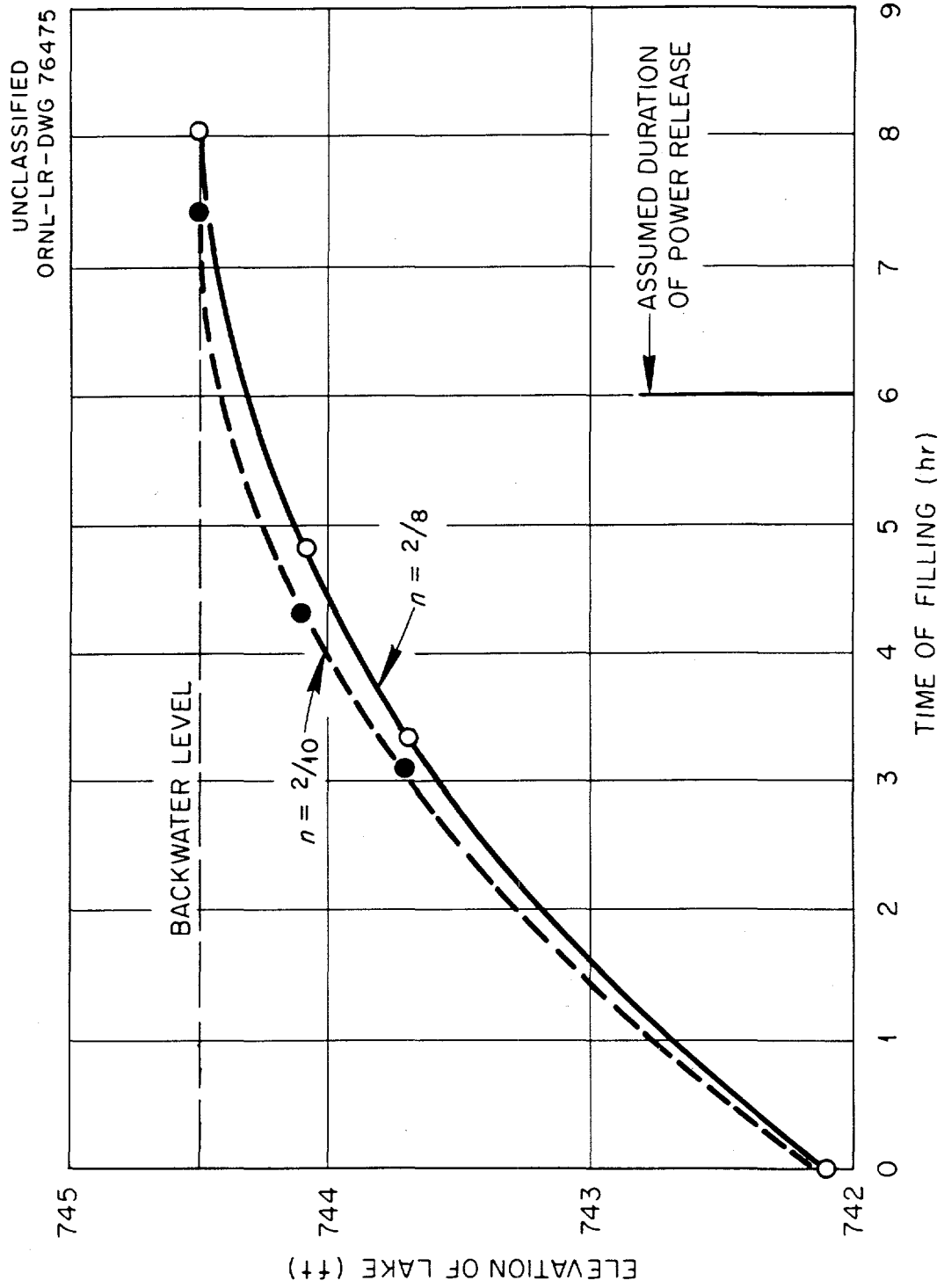
Fig. 11. Effect of Backwater due to Power Releases from Melton Hill Reservoir on Water Level in White Oak Lake.

The area of White Oak Lake which will be inundated in each case is shown in Fig. 10, and approximate percentages of flooding are given below.

Implications

If it were possible to exclude all discharges of radioactive liquid wastes from White Oak Creek the flow of the creek would be decreased by 0.2-0.4 cfs. This decrease in the inflow to White Oak Lake would not significantly affect the predicted lake levels. It is a practical necessity to release these contaminated liquid wastes.

For cases 2 and 3 the water levels may be as much as 3 feet higher on the downstream side of White Oak Dam, than on the upstream side. The ability of the dam, structurally, to withstand this differential force has been questioned.

For case 3, the concentration of radioactivity of waters in White Oak Lake may be decreased because inflow from Clinch River will provide additional dilution. For cases 1 and 2 no change in concentration may be expected because no change in the inflow of contaminants and of water will occur.

The rate of change in over-all concentration of radioactivity entering White Oak Lake will be very gradual. For this reason the dispersion of radioactivity in the lake should be fairly uniform for all three cases.

A considerable portion of the Ecology Study area will be flooded. For case 3, approximately 70% of the area will be flooded; case 2, 40 %; and case 1, 80%.

For all three cases the flow of White Oak Creek downstream from White Oak Dam into Clinch River will be cyclic, varying during

the day from no flow to flows that are equal to or a few times greater than 10 cfs. For case 1, the duration of no flow will be very short. The maximum flows from the creek into the river will occur when there is no flow in the river. Radioactive contaminants will then accumulate in a still pool,[18] and when power releases are made this accumulated radioactivity will be swept downstream.

Information presently available is not sufficient to predict the effects of the power releases on radioactivity levels in Clinch River downstream from the mouth of White Oak Creek.

Radiotracer Study of Dispersion and Dilution
February 1, 1962

Status Report No. 3 on the Clinch River Study included a report of a radiotracer study in Clinch River conducted on August 30-31, 1961.[19] The stated purpose was to: (1) investigate the areal extent of lateral dispersion; (2) find the point of relatively uniform stream-wide distribution of radioactivity; (3) determine the rate of reduction of maximum concentration of activity as the tracer moved downstream; and (4) investigate time of travel of the main body of activity from the point of injection to various points along the stream. The study was made during a period when the discharge in Clinch River was 7,990 cfs and water surface elevation in Watts Bar reservoir was 740.6 ± 0.2 ft. The report stated that "future studies are contemplated at extreme conditions of Clinch River discharge and Watts Bar reservoir elevation."

On February 1, 1962, discharge in the Clinch River was maintained at 20,200 cfs and the elevation of Watts Bar reservoir was 735.4

± 0.2 ft. At 9:09 a.m., 9.7 curies of Au^{198} in the form of gold chloride in a solution of hydrochloric and nitric acids was injected in a line across White Oak Creek at its mouth (CRM 20.8). The volume of tracer solution (obtained from ORNL) was 7.6 ml which was diluted with about 3000 ml of river water. The injection was made from a boat by releasing the tracer through a tube just below the water surface as the boat was moved across White Oak Creek, and was completed 80 seconds after the start. The discharge of White Oak Creek was 17 cfs.

Variation of radioactive concentration in the river water with time was determined with submerged scintillation detectors at several sections in the Clinch River downstream from the mouth of White Oak Creek (CRM 20.8). The sections at which these observations were made are listed in Table 11. The variations of radioactivity with time in each section are shown in Figs. 12-17.

The study was planned to include observations of the variation of radioactivity with time at a considerable number of sections and at several points in each section as was done in the study on August 30-31, 1961. However three of the five detectors prepared for the test became inoperative. The impact of the fast-moving water loosened the waterproof housing of the detectors and the circuitry was shorted. Therefore it was not possible to obtain as much data for this study as during the previous one. It was possible at CRM 14.5 and CRM 4.4 to observe the degree of development of full vertical dispersion (see Figs. 14 and 17).

From the curves shown in Figs. 12-17 the maximum and average concentrations of the tracer, the time of travel of the maximum

Table 11. Activity Levels and Travel Times in Tracer Study, February 1, 1962 (Probe 5 Feet below Water Surface, Except as Noted[a])

Cross Section Location (CRM)	Radioactivity (Corrected for Decay) (μμc/ml)		Time of Travel from Injection Point (hrs)		Duration of Activity > 1 μμc/ml (hrs)
	Maximum	Average	Maximum Activity	Center of Mass of "Slug"	
20.2	94.5	--[b]	0.4	--[b]	--[b]
17.5	17.4	6.1	1.4	1.5	0.8
14.5	12.9	4.9	2.8	3.0	0.9
12.0	8.1	3.2	4.1	4.1	1.0
9.0	6.6	2.8[c]	6.0	6.1[c]	1.2[c]
4.4	4.4	1.8	9.3	9.6	1.4

[a]At CRM 20.2, depth of probe was 3 ft; at CRM 14.5 and CRM 4.4, additional probe measurements at greater depths were also made (see Figs. 12, 14, and 17).

[b]Indicates no data available.

[c]Estimated--insufficient data for positive determination.
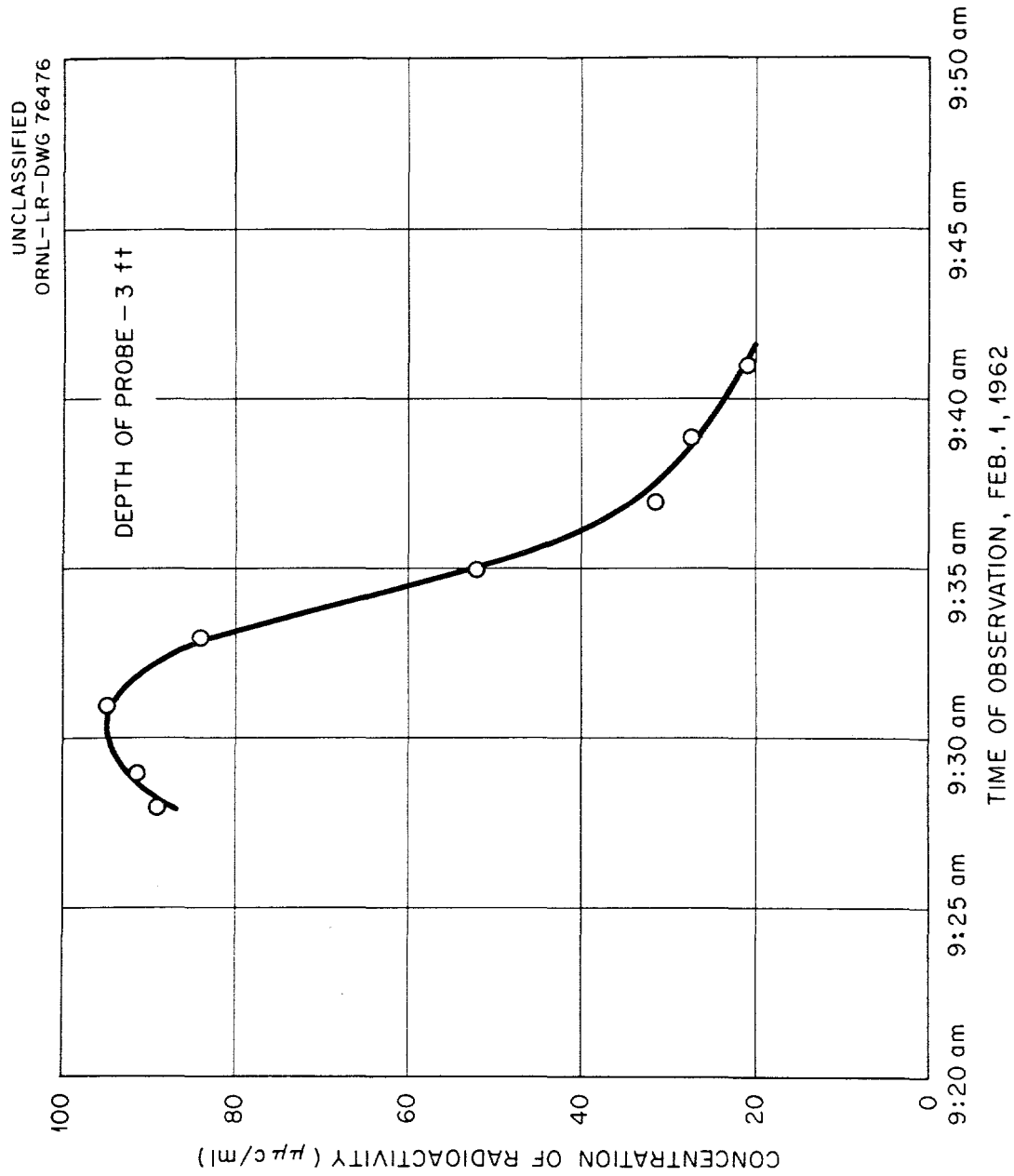
Fig. 12. Concentration of Au^{198} vs Time, Tracer Study of February 1, 1962, at CRM 20.2.
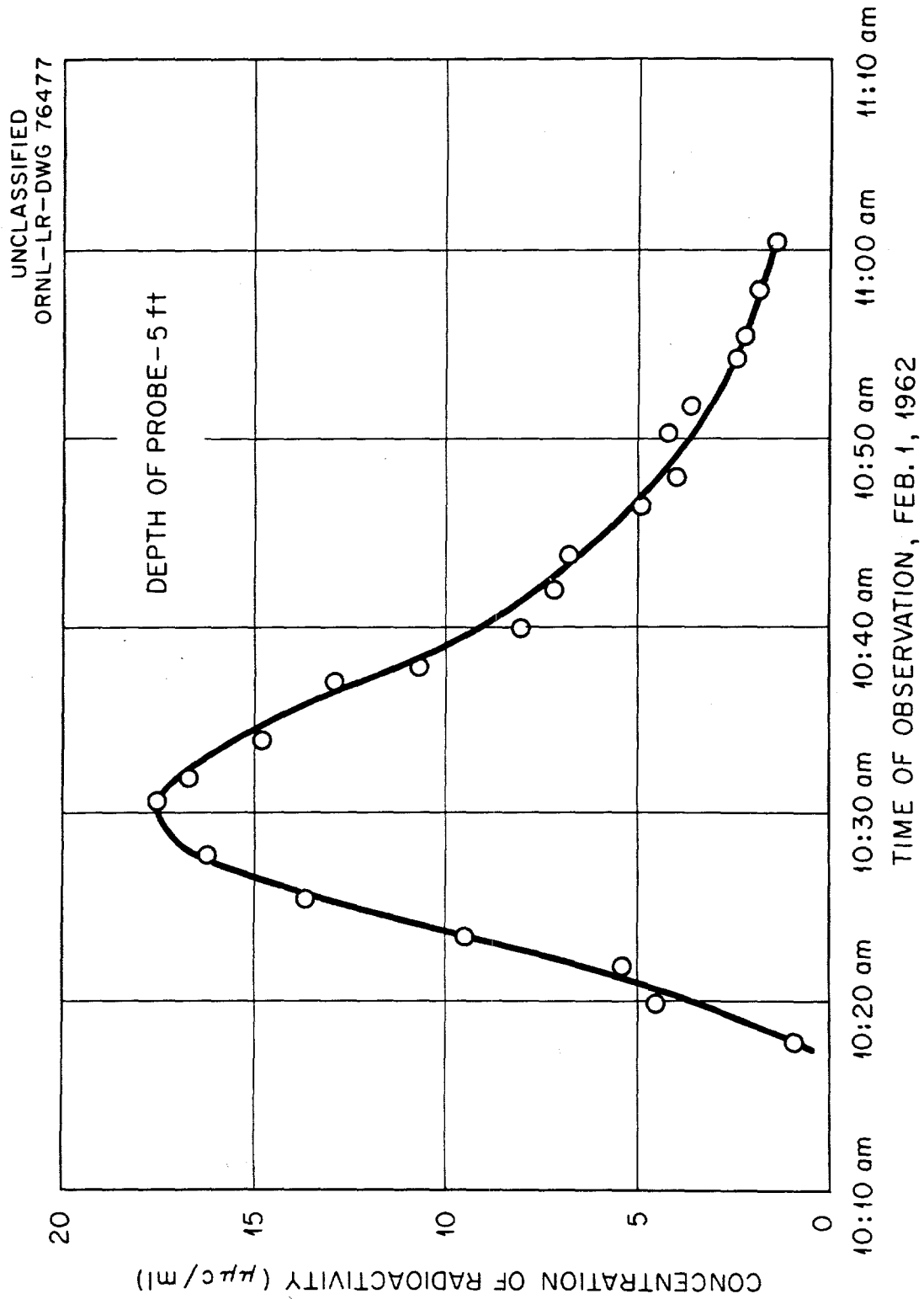
Fig. 13. Concentration of Au[198] vs Time, Tracer Study of February 1, 1962, at CRM 17.5.

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DEPTH OF PROBE – 5 ft (EXCEPT AS NOTED)
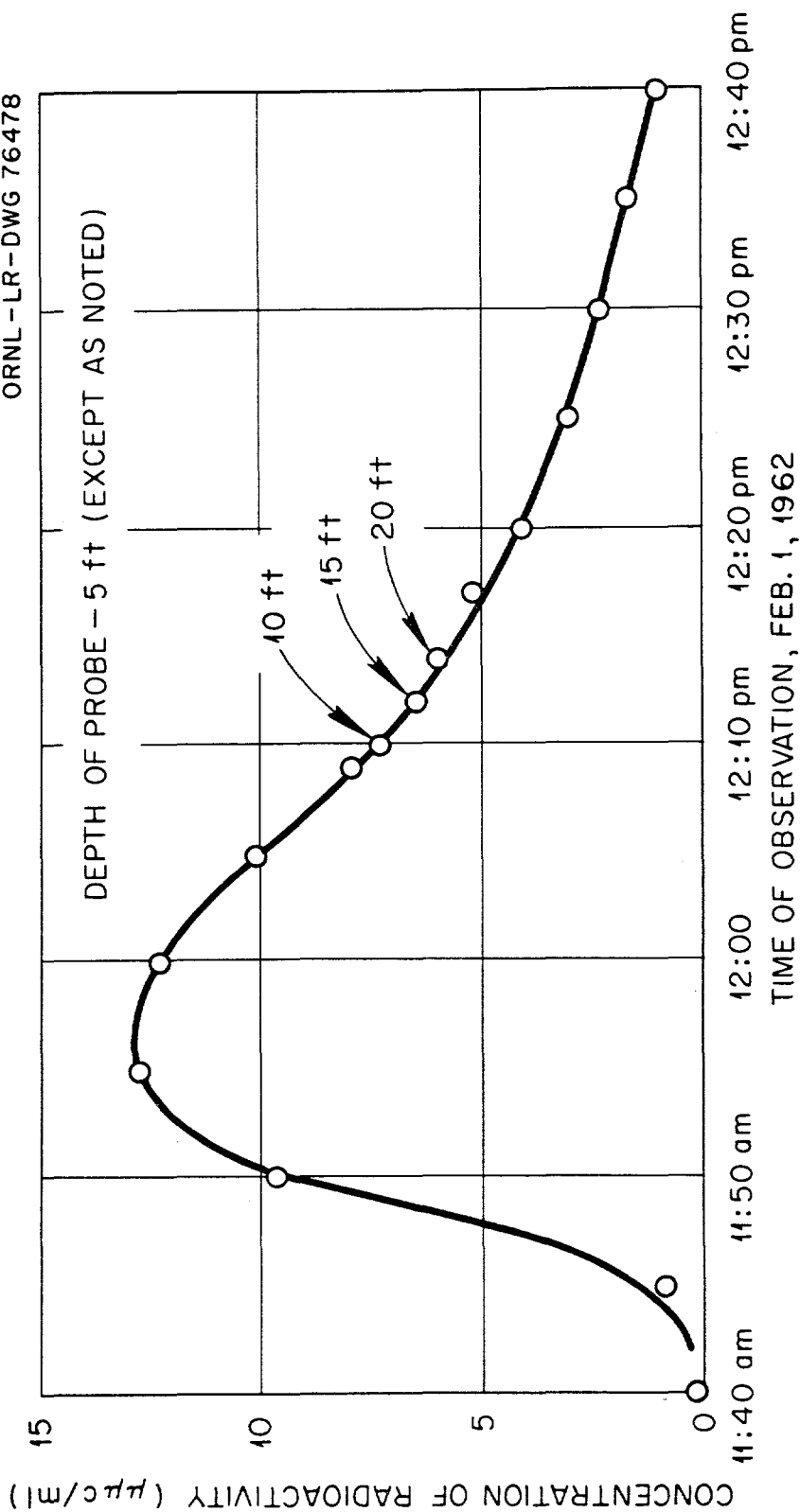
Fig. 14. Concentration of Au^{198} vs Time, Tracer Study of February 1, 1962, at CRM 14.5.
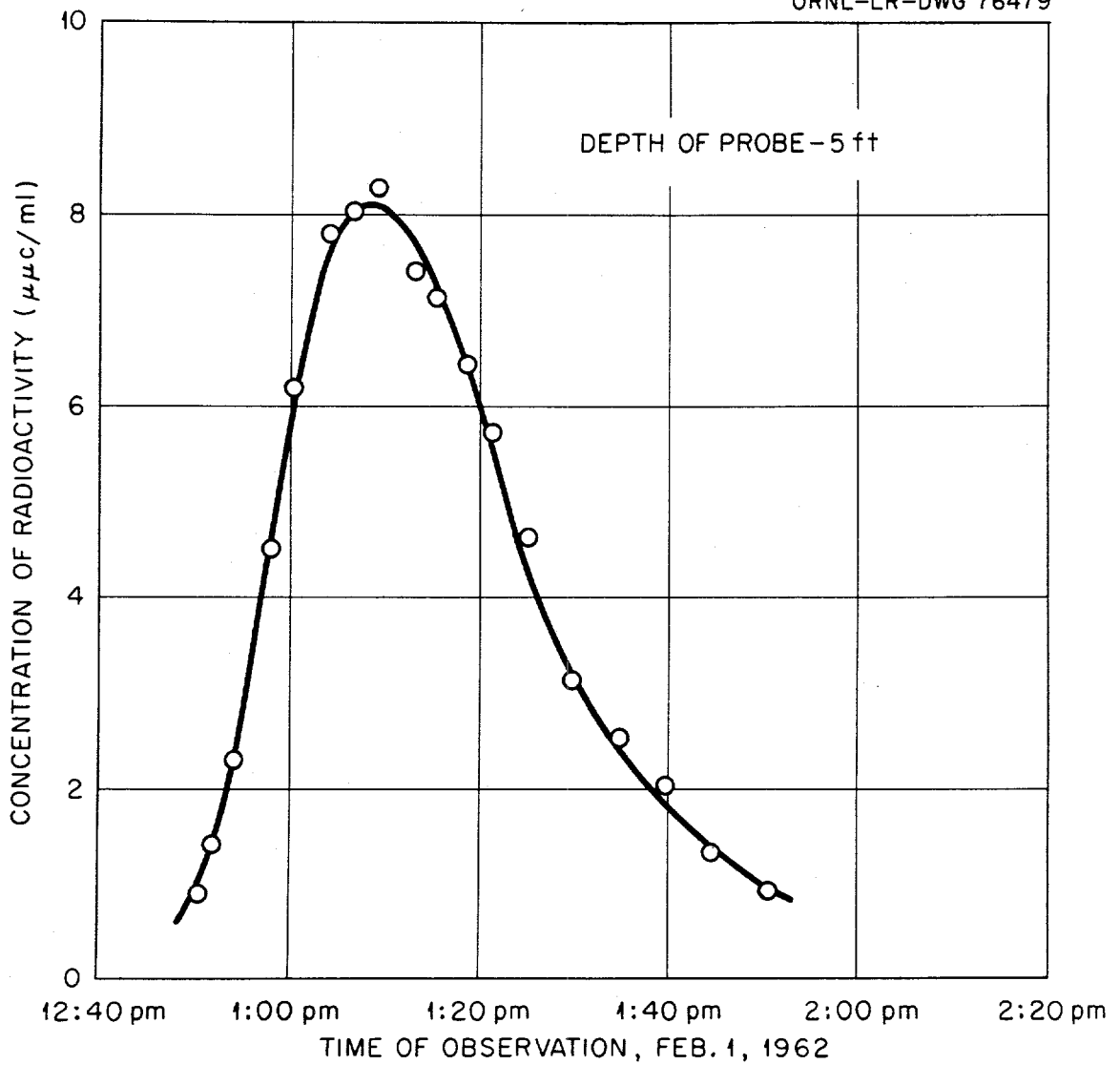
Fig. 15. Concentration of Au^{198} vs Time, Tracer Study of February 1, 1962, at CRM 12.0.
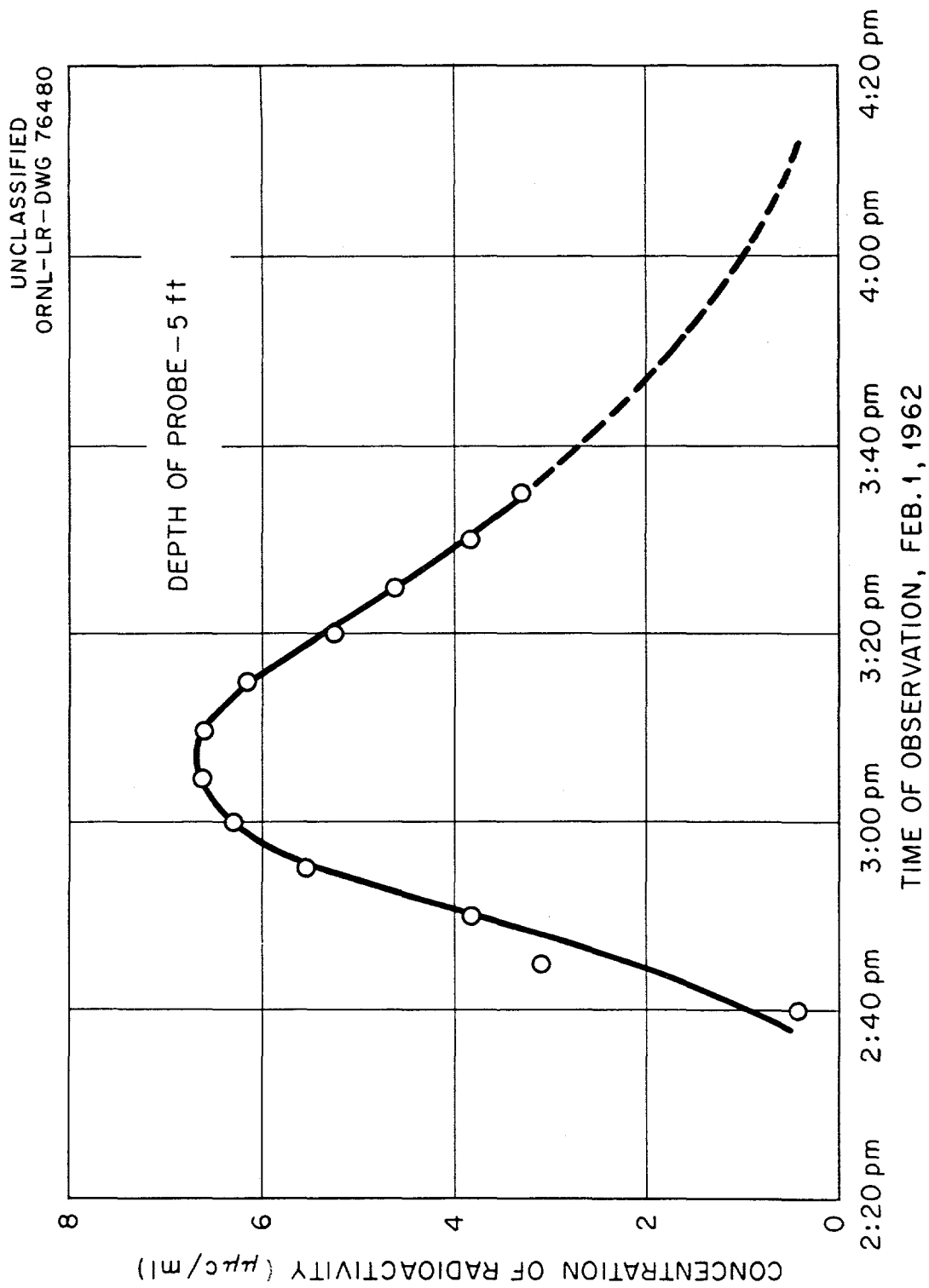
Fig. 16. Concentration of Au[198] vs Time, Tracer Study of February 1, 1962, at CRM 9.0.
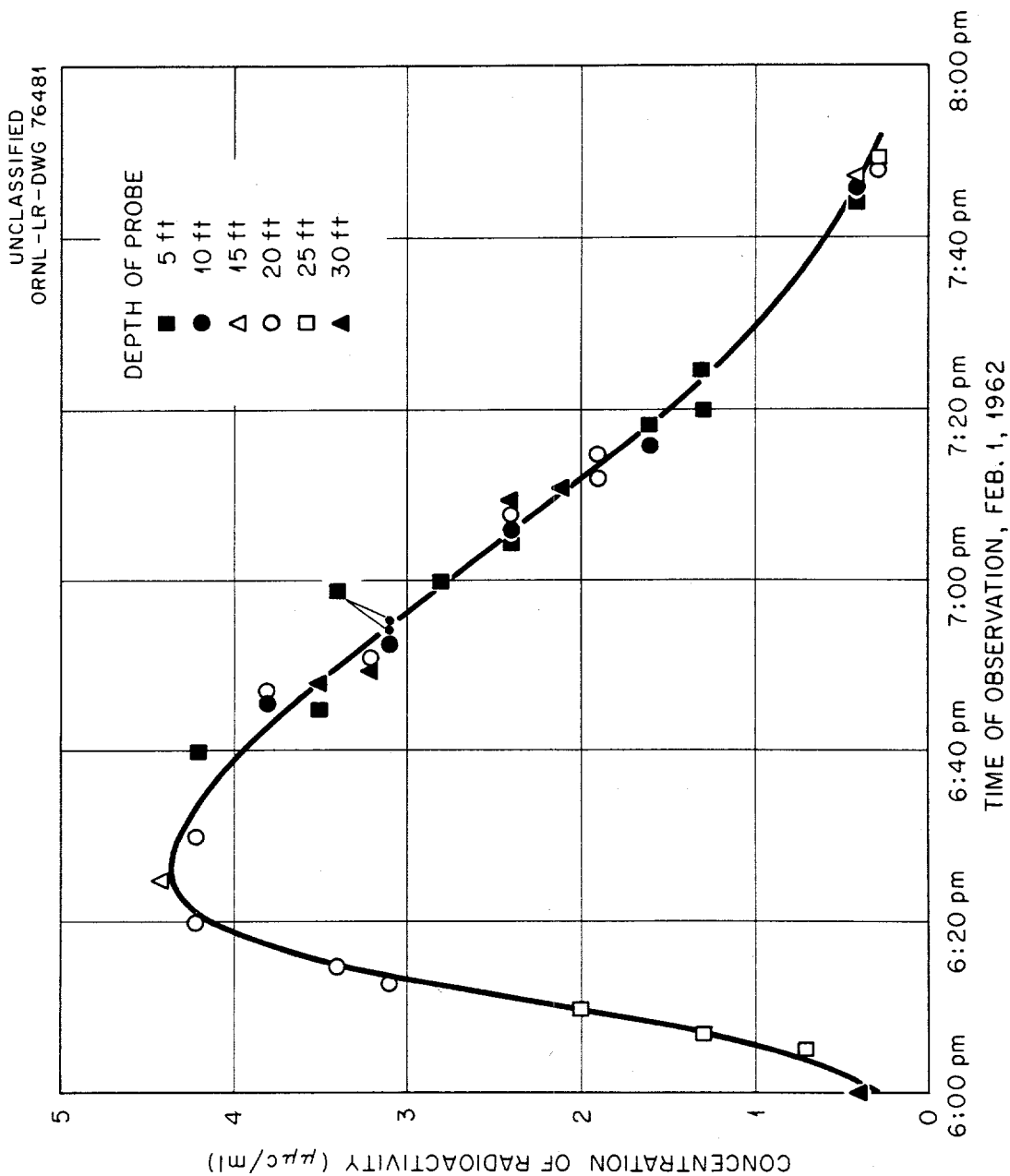
Fig. 17. Concentration of Au^{198} vs Time, Tracer Study of February 1, 1962, at CRM 4.4.

concentration and of the center of mass of the tracer, and the duration

of the tracer were determined for each section. These values are listed

in Table 11.

The relationship of maximum concentration to travel distance is

shown in Fig. 18. The very definite change in slope of the curve

between CRM 20 and CRM 17 suggests that the dispersion of the tracer

over the entire cross-sectional area of the stream occurred somewhere

between these sections. It is unfortunate that field data were not

collected either in the vertical or at different cross-stream points

at CRM 17.5 to substantiate this statement. However in the study of

August 30-31, 1961 a similar change in slope of the curve of maximum

concentration versus distance was noted and data collected during the

study indicated stream-wide dispersion of the tracer in the vicinity

of this change in slope. A plot of the reduction in peak concentration

with location of cross section for the August 1961 and February 1962

studies, as shown in Fig. 19, also suggests that dispersion of the

tracer over the entire cross-sectional area occurred between CRM 18

and CRM 15 in each study.

A comparison of the maximum concentration of radioactive tracer

with travel distance for each study is shown in Fig. 20. For this

comparison the ratio of peak concentration at each observed cross

section to the peak concentration at CRM 4.4 was plotted. The plots

indicated very similar variations for the two studies.

Further Study of Variability of Dilution Factors

In Status Report No. 3 on Clinch River Study[19] the variation

of monthly dilution factors with time, the duration curve for daily
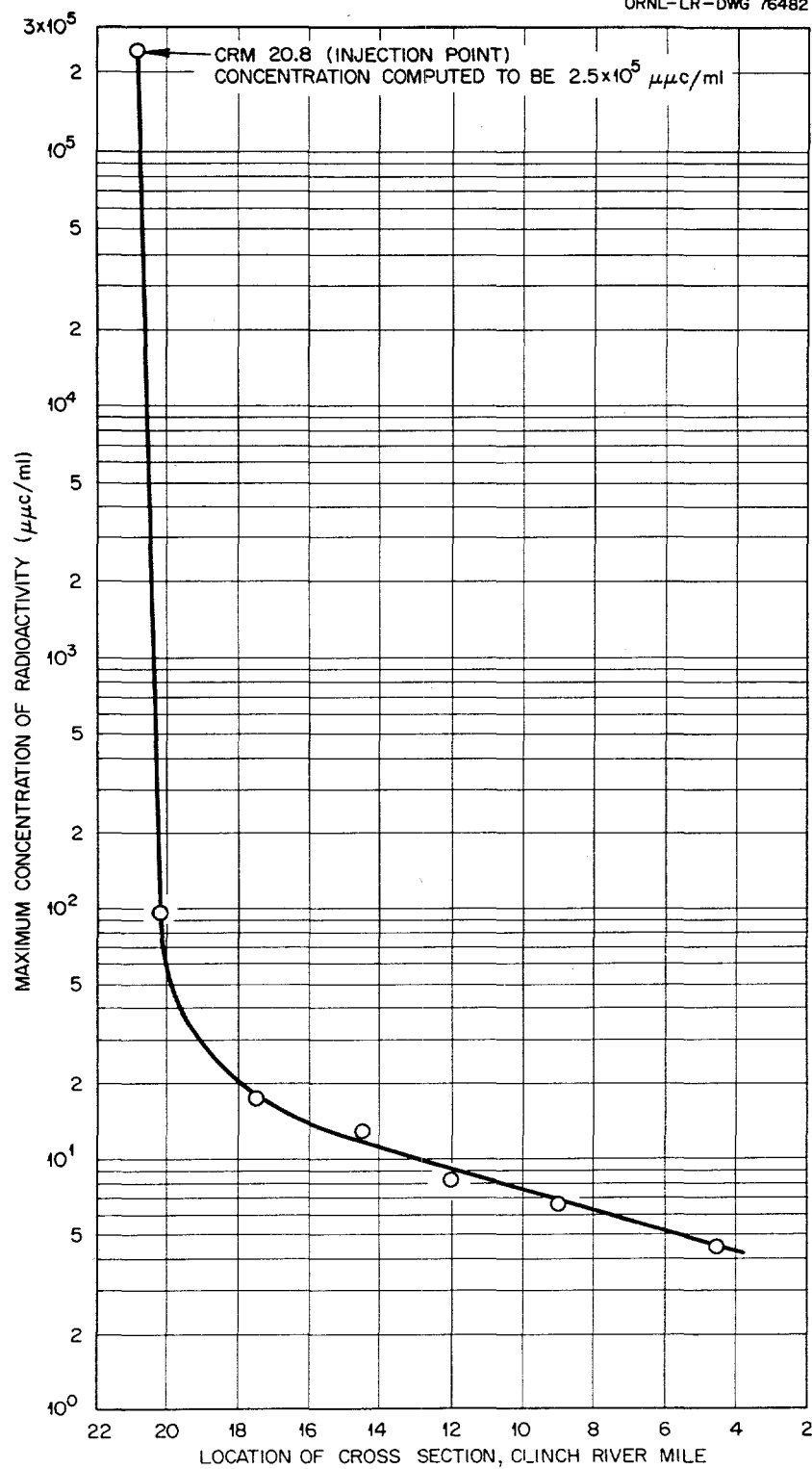
Fig. 18. Variation of Maximum Concentration of Au[198] with Distance, Tracer Study of February 1, 1962.
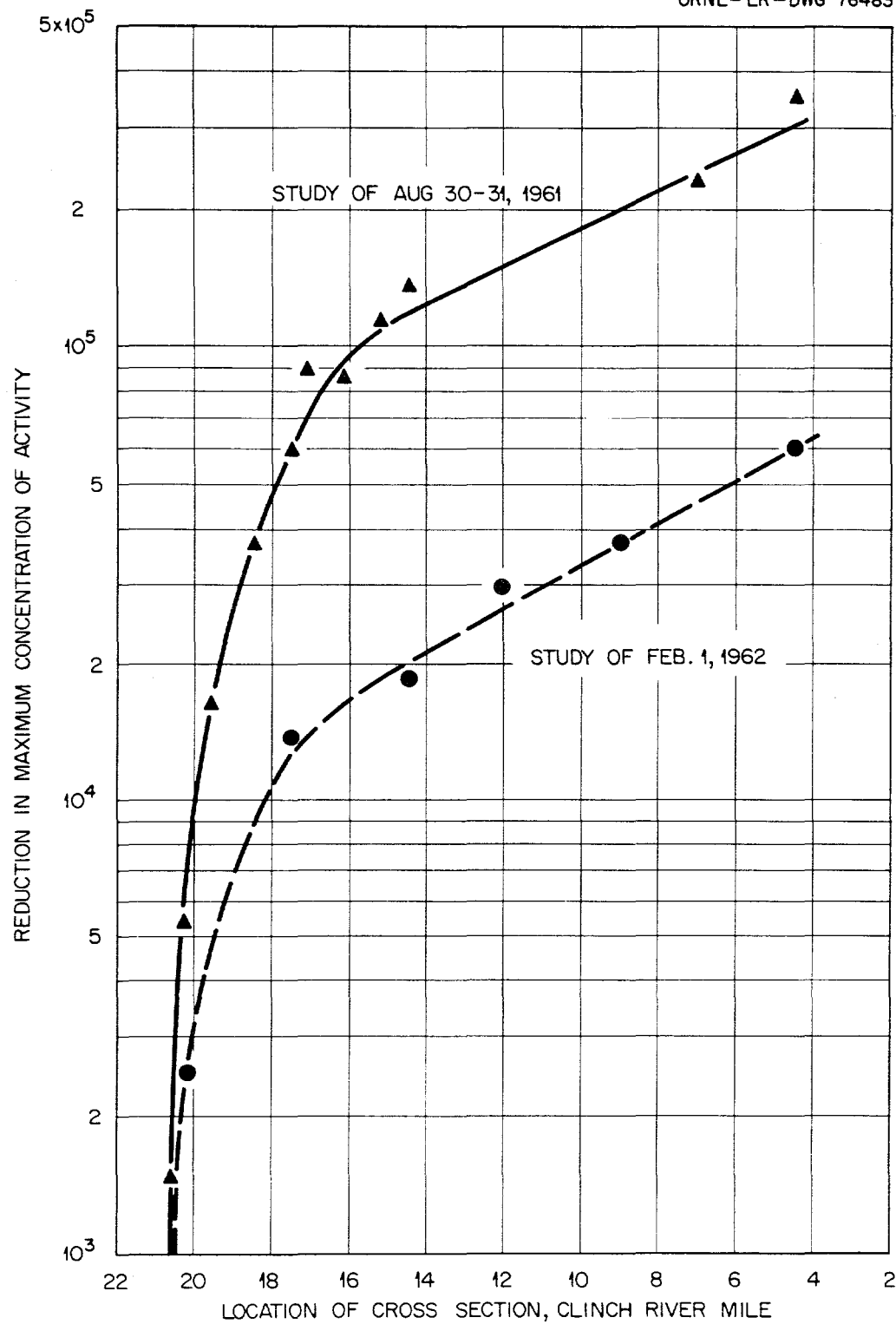
Fig. 19. Magnitude of Reduction of Maximum Concentration of Au[198] with Distance during Two Tracer Studies in Clinch River.
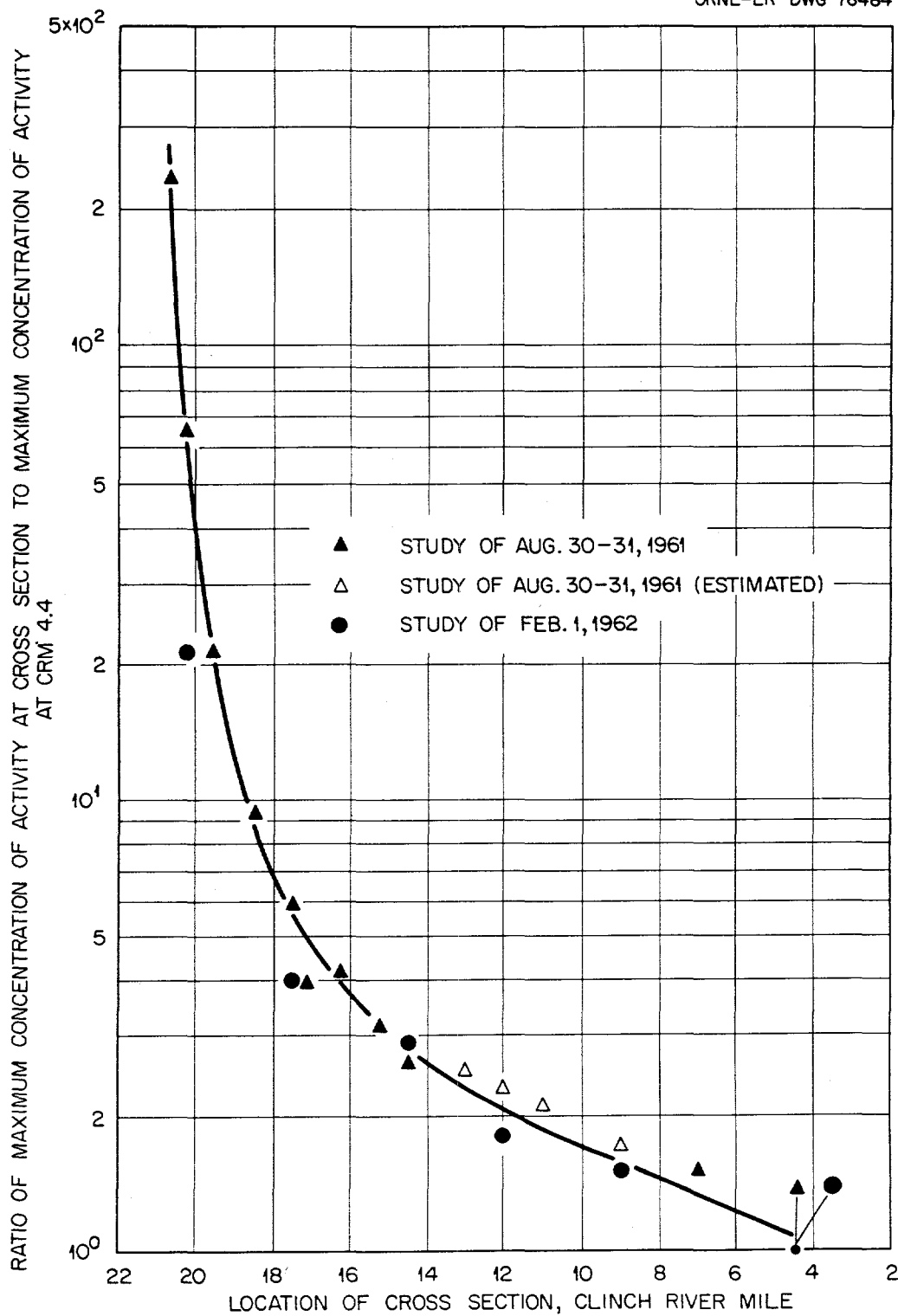
Fig. 20. Comparison of Relative Maximum Concentrations of Au^{198} during Two Tracer Studies in Clinch River.

dilution factors, and frequency curves for the minimum monthly and minimum daily dilution factors were reported. The dilution factor has been defined as the ratio of the discharge in Clinch River near Scarboro, Tennessee, to the discharge in White Oak Creek at White Oak Dam, near Oak Ridge, Tennessee for concurrent periods. The base period which was selected for study is October 1, 1950 to September 30, 1960.

In further study of the variability of dilution factors during the 10-year period, the duration of daily dilution factors by five-day periods was determined. The results were plotted to show the values of daily dilution factors that had been exceeded 1/10, 1/4, 1/2, 3/4, and 9/10 of the time for each of the 73 five-day periods in the January-December time scale. Again, this analysis showed seasonal trends, with daily dilution factors lower in the winter and early spring than in the summer and early fall. For example, the daily dilution factors for the "median" curve (equalled or exceeded 1/2 of the time) ranged from 150 to 1050. In February, March, and April the median value was less than 500; from June through October, it was equal to or greater than 500. In the duration curve for daily dilution factors shown in Status Report No. 3[19] the median dilution factor was 570.

Frequency studies of minimum dilution factors of specified duration which occur annually have been made. These durations are 1, 3, 7, 15, and 30 days. Results of these studies are shown in Fig. 21. The recurrence interval is the average interval of time within which a dilution factor will be less than or equal to a given magnitude once.

In Fig. 21, the dotted curve is that reported in Status Report No. 3,[19] for the minimum monthly dilution factors. It will be noted that this curve is below that for a 30-day duration. This difference results from methods of computation used to develop the curves. The curve for the minimum-30-day dilution factor is based on the ratio of the mean daily flows occurring in Clinch River and White Oak Creek. The curve for the minimum monthly dilution factor, labelled "monthly means," is based on the ratios of mean monthly flows occurring in the two streams. As described in Status Report No. 3,[19] records of flows for White Oak Creek at White Oak Dam were not available for the entire base period. Flows for the missing periods were determined from records for the gaging station White Oak Creek below ORNL near Oak Ridge (see Table 8), by means of correlation curves. The mean monthly flows for White Oak Creek at White Oak Dam are, in many instances, the correlative product of the mean monthly flow for White Oak Creek below ORNL.
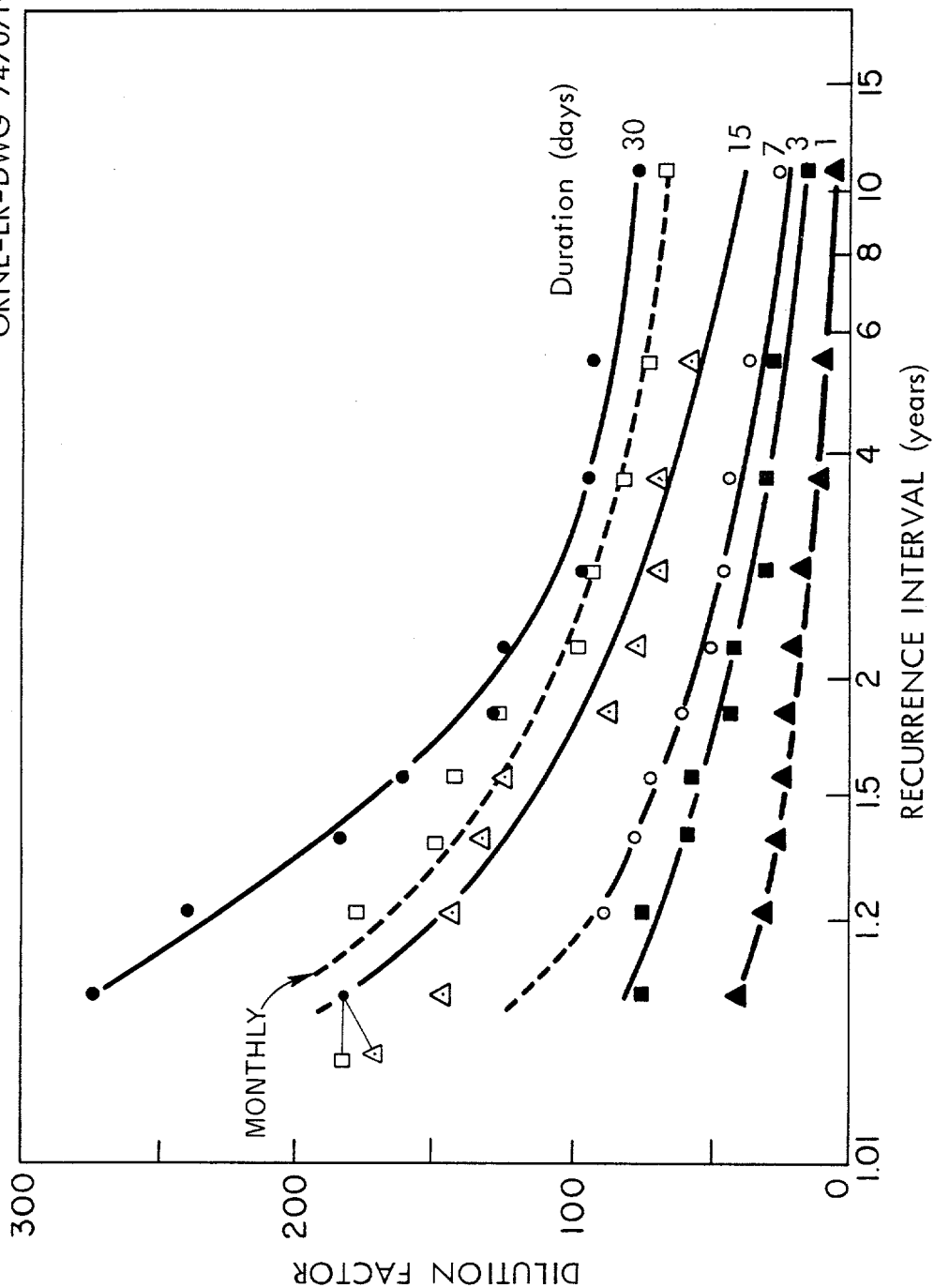
Fig. 21. Minimum Dilution Factor Frequency Curves for 1, 3, 7, 15, and 30 days, Annual Series.

SAFETY EVALUATION STUDIES

Introduction

The Subcommittee on Safety Evaluation was established by the Steering Committee October 27, 1961," to study available information and additional data that may be obtained and evaluate the potential hazards of discharges of radioactive wastes from Oak Ridge installations in the Clinch and Tennessee Rivers."[20] In subsequent meetings of the subcommittee, one jointly with the Steering Committee, the scope of safety evaluation expected was defined, exposure pathways of released radioactive wastes to be considered were outlined, and preliminary information on various uses of Clinch and Tennessee River water that might cause radiation exposures was assembled. The results of these earlier efforts by the subcommittee were summarized in Progress Report No. 1, submitted to the Steering Committee at its meeting on April 26, 1962.[21]

During the period May 1962 to January 1963, the subcommittee, with staff assistance by K. E. Cowser of the ORNL waste research group, has undertaken detailed analyses of available data. This work has included calculations of estimated radiation doses that might be attained from human exposures to radioactive materials in the river system through the various exposure pathways. A preliminary report on the results of these analyses to date, and an outline of additional information needed by the subcommittee, were given in Progress Report No. 2 which was submitted at a meeting of the Steering Committee February 6-7, 1963.[22]

This section of the present report (Status Report No. 4) is based on the two progress reports mentioned above. From Progress Report No. 2, which is still incomplete, the preliminary estimates of potential dosages from drinking water, immersion in the water, and contaminated bottom sediments are summarized.

Bases of Evaluation

When radioactive material is released to a body of water, there is a complex network of mechanisms by which the material is transmitted from one component, animate or inanimate, to another. At each point in the network or chain of transmission, human or other life forms may be subject to some degree of radiation exposure.

The probability that exposure will occur and the degree of exposure depend upon many complex and interrelated factors. The approach adopted by the subcommittee is to assemble as much specific information as possible about each of the avenues of human exposure to be considered (see pp. 87 and 91); and then, with conservative assumptions, to make quantitative estimates of the radiation dosages that might be received by various population groups.

To be realistic, these estimates of dosages must be based upon factual data or trustworthy assumptions regarding relevant conditions in the stream and surrounding areas. Information is needed, for example, about the population area that may be affected, the numbers of people and their habits which may affect the nature of exposure, the sources, types, and quantities of radionuclides released to the river system, and the concentrations of the principal radionuclides in the media of human exposure, e.g., water, sediments,

fish, irrigated food crops, and operational processes that may concentrate the radionuclides. Furthermore, interpretation of the available data and evaluation of the over-all situation in terms of safety requires detailed data regarding many other environmental factors. In general this information is provided by field and laboratory studies of hydrologic, physical, chemical, and biological parameters.

In the Clinch River Study the Subcommittee on Safety Evaluation depends primarily upon other groups and subcommittees to provide the descriptive and analytical data needed to define exposure factors. Criteria of permissible radiation exposures, adopted by national and international agencies, are accepted as guides. On these bases the subcommittee is making conservative estimates of the human exposures that may result from the Clinch-Tennessee River contamination, and reaching conclusions regarding their importance.

In its work to date the subcommittee has summarized the available data on quantities of radionuclides released to Clinch River, and has reviewed the methods of estimating dosages of radiation and the permissible limits of exposure. Preliminary estimates have been made of exposures that might be caused by radionuclides in the Clinch-Tennessee River system through drinking water, immersion in contaminated water, and contaminated bottom sediments. The results of this part of the subcommittee's work are summarized in this section of the present report.

Objectives

The immediate objective of the subcommittee is to evaluate the potential effect of each relevant pathway in causing radiation exposure

to man. The most direct means of evaluating internal exposures is to determine the amounts of radioactive material in the bodies of exposed members of population groups, for example, by whole-body counting or body-fluid analyses. Lacking such data at present, exposures are being calculated from measurements of the amounts of radioactive material in the various environmental media, and assumptions as to the fraction of this material that may affect the exposed population.

The long-range objectives of the subcommittee is evaluation of the total potential effect of radioactivity in the environment in causing exposures through the river system, and delineation of exposure pathways so as to understand the prevailing levels of safety for animal and plant life. In this respect, the subcommittee hopes to establish parameters of downstream safety which will be applicable to the environment as well as to man and under many combinations of conditions.

Further Information Needed

The values obtained and presented in this report are believed to be conservative. It is emphasized, however, that the calculated estimates of potential exposures are tentative because, lacking data from actual measurements, a number of assumptions were necessary in order to complete the calculations. For example, data from analyses in progress which are not yet available include: water samples collected during the past year, extensive core-sampling of bottom sediments in Clinch River during 1962, a large sampling of different species of fish for which data are essential, and samples to determine

the build-up of fission products in three water treatment plants and distribution systems on Clinch River, one upstream and two downstream from Oak Ridge. No data on measured radiation levels or analyses are available to indicate potential dosages from food crops or milk produced where land is irrigated with river water. When available, results from the whole-body counting study of a small number of workers at the Oak Ridge Gaseous Diffusion Plant (ORGDP) may be helpful in evaluating exposures through drinking water. Also, external radiation measurements, where possible, to confirm calculations of dose rates from the measured concentrations of radionuclides, as in water or sediments, would strengthen confidence in the estimated exposure values.

Additional Data Collection Recommended

The subcommittee stated that the data outlined below are needed to provide more reliable observed values and/or to substantiate assumptions upon which the tentative estimates of exposure are based. It was recommended that, in so far as is feasible, these data should be obtained and made available.

1. Data from analyses in progress (mentioned above). - river water, sediments, fish, water supply systems, and whole-body counting of ORGDP employees.

2. Measurements relative to crop irrigation. - for example, radiological analyses of irrigation water, soil, food crops, and milk from irrigated farms and unirrigated areas (controls); and related information about irrigated crops and methods of irrigation used.

3. Measurements relative to water immersion. - radiation
levels in the river water, especially in swimming and recreation
areas of the rivers.

4. Contaminated sediments. - measurements of radiation
emitted from submerged sediments and from exposed shoreline banks
where people may be exposed while swimming, fishing, etc.

Radionuclides Released and Concentrations in the Rivers

Virtually all the radioactivity emanating from the Laboratory
and reaching the Clinch River passes through White Oak Creek. The
final control point for wastes released to the river (CRM 20.8) is
at White Oak Dam.

The flow of water through White Oak Dam has been determined
by two methods.[23,24] During the period 1953-1955, while White Oak
Lake was still impounded, a gaging station at the dam was used.
After 1955, when the lake was drained and the gaging station
inactivated, flow was calculated by summing the separate measurements
of flow in White Oak Creek upstream from Melton Branch and in Melton
Branch which are the principal contributors of surface drainage.
The gaging station at the dam was reactivated in 1960 and since that
time has been used for flow measurements.

Until 1947, daily radiation measurements were made and periodic
samples were collected at White Oak Dam. The gross-beta activity
was determined, and, coupled with estimated daily flow, the number
of beta curies released each day was calculated. Currently,
calculations are in progress to estimate at least the gross activity
released during the period, 1943-1947. Beginning in 1949, monthly

composite samples were also analyzed radiochemically for cesium, ruthenium, strontium, cobalt, trivalent rare earths (TRE), cerium, zirconium, niobium, and iodine; and the curies of each radionuclide released each year was calculated (Table 12). The increase in the quantity of Cs^{137} released in 1955 was attributed to the draining of White Oak Lake. Subsequent reductions in releases of Cs^{137} and of Sr^{90} resulted from treatment of process waste water. The increase in Ru^{106} released was caused by operation of the waste pits.

Estimates of the mean annual concentrations of radionuclides in the Clinch and Tennessee Rivers are based on dilution ratios and the fact that the effluent of White Oak Creek is completely mixed with the river after about 3-5 miles of flow downstream from the mouth of the creek. This was shown by three tracer tests in the Clinch River in 1958, 1961, and 1962.[25,26,27] The concentration values derived in this way are consdrvative since no allowance is made for decreases of the radioactivity in the water, for example, removal and deposit in bottom sediments. From a preliminary assessment of the total radioactivity in Clinch River sediments it is believed that, of releases since 1943, approximately 300 curies of the long-lived Sr^{90}, Cs^{137}, and Ru^{106} are incorporated in these sediments.[28] More reliable estimates of total activity in bottom sediments should be possible when the results of analyses of the 1962 core samples, now in progress, are available.

Availble information concerning river water usage downstream from ORNL was assembled by the subcommittee in its first progress report.[21] Use of river water for downstream community water-supply systems in Tennessee is summarized in Table 13, which shows that

Table 12. Yearly Discharges of Radionuclides to Clinch River (curies)[a]

Year	Gross Beta	Cs^{137}	Ru^{106}	Sr^{90}	Tre(-Ce)	Ce^{144}	Zr^{95}	Nb^{95}	I^{131}	Co^{60}
1949	718	77	110	150	77	18	180	22	77	
1950	191	19	23	38	30		15	42	19	
1951	101	20	18	29	11		4.5	2.2	18	
1952	214	9.9	15	72	26	23	19	18	20	
1953	304	6.4	26	130	110	6.7	7.6	3.6	2.1	
1954	384	22	11	140	160	24	14	9.2	3.5	
1955	437	63	31	93	150	85	5.2	5.7	7.0	6.6
1956	582	170	29	100	140	59	12	15	3.5	46
1957	397	89	60	83	110	13	23	7.1	1.2	4.8
1958	544	55	42	150	240	30	6.0	6.0	8.2	8.7
1959	937	76	520	60	94	48	27	30	0.5	77
1960	2190	31	1900	28	48	27	38	45	5.3	72
1961	2230	15	2000	22	24	4.2	20	70	3.7	31

[a]Values calculated from data supplied by Applied Health Physics Section, ORNL.

Table 13. Community Water Systems in Tennessee Downstream from
ORNL Supplied by Intakes on Clinch and Tennessee Rivers or
Tributaries That May Be Affected by Main Stream Conditions

Community	Intake Source		Number of Services	Population Served	Quantity (MGD)	Remarks
	Stream	Location				
ORGDP K-25	Clinch R.	CRM 14.5		3,015	4	Industrial plant potable water system.
Harriman	Emory R.	ERM 12	2,858	12,000	1.15	May at times draw Clinch R. water.
Kingston Steam Plant	Clinch R.	CRM 3		600	.05	Potable water system.
Kingston	Tenn. R.	TRM 570	1,265	6,500	.29	River supplements spring supply.
Watts Bar Dam and Resort	Tenn. R.	TRM 530	25	150	.03 .14	Summer population highly variable.
Soddy–Daisy–Falling–Walden's Ridge	Tenn. R.	TRM 488	2,545	8,000	.4	Supply approximately 3/4 from river, 1/4 from well.
Harrison Bay State Park	Tenn. R.	TRM 478		50	.05	Population highly variable. Swimming pool separate.
Booker T. Washington State Park	Tenn. R.	TRM 474			.05	Supplies swimming pool only.
Chattanooga	Tenn. R.	TRM 465	50,000	225,000	38.0	Includes Signal Mountain
Rockwood	Tenn. R.	TRM 555	2,000	7,000	1.0	River supplements spring supply.
Spring City	Piney R.	PRM 6.4	611	1,850	.15	Piney R. supplements spring supply.
South Pittsburg	Tenn. R.	TRM 435	1,300	4,000	.4	

more than a quarter-million people obtain domestic water supplies
from river sources.

A resume of agricultural usage of water on the Clinch River
between ORNL and Kingston stated that there are 27 farms bordering
the Clinch River, with an average of 5 persons per farm, a total of
about 5000 acres, all using the river for watering about 500 head of
livestock, but obtaining potable water from wells, springs, and
cisterns. Regarding irrigation, there was no use of water from
Clinch River for irrigating crops. Of two farms in the vicinity of
Kingston irrigating about 15 acres of corn and watermelons, one took
water from the Emory River and the other from the Tennessee River
downstream from the mouth of Clinch River.

Four downstream locations were selected for the evaluation
analyses, namely: (1) Clinch River Mile (CRM) 14.5 (which is
6.3 miles downstream from the White Oak Creek discharge at CRM 20.8);
(2) CRM 2.6 (downstream from mouth of Emory River and near Kingston
Steam Plant); Tennessee River Mile (TRM) 529.9 (Watts Bar Dam);
and TRM 465.5 (at Chattanooga water supply intake and 5.5 miles
downstream from Chickamauga Dam).

At CRM 14.5 and in the vicinity of CRM 2.6 water supplies
taken from the river are used by ORGDP and the Kingston Steam
Plant, respectively, for sanitary and industrial purposes. There
are downstream recreational areas at the Kingston waterfront, at
Watts Bar Dam, and at numerous places along Watts Bar reservoir.
There are large recreational areas along Chickamauga Reservoir, notably
just above Chickamauga Dam (CRM 471.0). The first large population

center (Chattanooga, Tennessee) is located a few miles downstream from Chickamauga Dam (TRM 471.0) and is served by a public water supply taken from the Tennessee River at TRM 465.5. In addition, CRM 14.5, TRM 529.9, and TRM 471.0 are stations in the basic water-sampling network of the Clinch River Study, which will allow the determination of actual concentrations of radionuclides at these locations to be made.

The quantity of water passing each location annually was calculated from average flow values (Table 14). The average concentrations of radionuclides at each location was determined from the curies released and the total flow for each year. In this report the calculated concentration values for two of the locations are given; namely, CRM 14.5 and TRM 465.5 (Tables 15 and 16).

Avenues of Human Exposure

The potential avenues of human exposure resulting from release of radioactivity to the environment are many and complex. H. M. Parker has conceived of a number of exposure pathways and has indicated those which he believes to be of major consequence.[29] From radioactive wastes in rivers, streams, lakes, or reservoirs he emphasizes the hazards related to use as drinking water, immersion in the water, close approach to the water (including contaminated mud and vegetation), use of water for irrigation, uptake by biological chains, industrial processes, sewage disposal, and atmospheric discharges.

The list is well conceived, but, unfortunately, includes many avenues for which data are not currently available. A complete

Table 14.   Mean Annual Flow in Clinch and Tennessee Rivers
(cubic feet per second)

YEAR	CRM 14.5[a]	CRM 2.6[a]	TRM 529.9[b]	TRM 471.0[b]
1943	5310	6620	26130	32330
1944	4800	6870	25690	32290
1945	4940	7020	26490	32270
1946	5150	6880	29100	38540
1947	4420	5720	24040	31190
1948	4290	6480	26370	34360
1949	5460	7560	33300	43630
1950	6630	9360	34240	44030
1951	6170	8760	28070	36560
1952	4570	5770	22470	29770
1953	4340	5710	22160	28130
1954	2990	4730	20480	26050
1955	4850	6610	23790	30530
1956	5040	7340	24750	30990
1957	6350	9300	36310	45250
1958	5560	6880	27780	34330
1959	3490	5260	23760	29000
1960	4460	6200	25150	31010
1961	4780	7110	29520	37430

[a]VALUES FURNISHED BY THE UNITED STATES GEOLOGICAL SURVEY – ESTIMATED ON BASIS OF DISCHARGE RECORDS FOR THE GAGING STATION ON CLINCH RIVER NEAR SCARBORO AND INTERVENING INFLOW.

[b]VALUES FURNISHED BY THE TENNESSEE VALLEY AUTHORITY.

Table 15. Calculated Mean Annual Concentration of Radionuclides at Clinch River Mi. 14.5 (Units of 10^{-9} µc/ml or µµc/liter)

Year	Gross Beta	Cs^{137}	Ru^{106}	Sr^{90}	Y^{91}	Ce^{144}	Zr^{95}	Nb^{95}	I^{131}	Co^{60}
1949	150	16	22	30	0	3.7	36	4.6	16	
1950	32	3.2	3.9	6.5	0		2.5	7.2	3.2	
1951	18	3.6	3.2	5.2	0		0.82	0.40	3.2	
1952	53	2.4	3.6	18	0	5.6	4.7	4.4	4.8	
1953	78	1.7	6.8	35	0	1.7	2.0	0.93	0.54	
1954	140	8.2	4.2	51	11	8.9	5.2	3.5	1.3	
1955	100	15	7.1	22	13	20	1.2	1.2	1.6	1.5
1956	130	38	6.5	23	7.6	13	2.6	3.4	0.78	10
1957	70	16	11	15	5.5	2.2	4.0	1.3	0.21	0.85
1958	110	11	8.4	30	18	6.0	1.2	1.2	1.7	1.8
1959	300	25	170	19	11	16	8.7	9.5	0.16	24
1960	550	7.7	480	6.9	5.1	6.7	9.3	11	1.3	18
1961	520	3.5	480	5.2	0.35	0.98	4.6	17	0.87	7.3

Table 16. Calculated Mean Annual Concentration of Radionuclides at Tennessee River Mi. 465.5 (Units of 10^{-9} μc/ml or μμc/liter)

Year	Gross Beta	Cs^{137}	Ru^{106}	Sr^{90}	Y^{91}	Ce^{144}	Zr^{95}	Nb^{95}	I^{131}	Co^{60}
1949	18	2.0	2.7	3.7	0	0.46	4.5	0.57	2.0	
1950	4.9	0.49	0.60	0.98	0		0.38	0.11	0.49	
1951	3.1	0.61	0.54	0.87	0		0.14	0.068	0.54	
1952	8.1	0.37	0.56	2.7	0	0.86	0.72	0.68	0.74	
1953	12	0.26	1.1	5.4	0	0.27	0.30	0.14	0.083	
1954	17	0.94	0.48	5.8	1.2	1.0	0.59	0.40	0.15	
1955	16	2.3	1.1	3.4	2.0	3.1	0.19	0.21	0.26	0.24
1956	21	6.2	1.1	3.8	1.2	2.1	0.42	0.55	0.13	1.7
1957	9.8	2.2	1.5	2.1	0.78	0.31	0.56	0.18	0.030	0.12
1958	18	1.8	1.4	4.8	3.0	0.97	0.20	0.20	0.32	0.28
1959	36	2.9	20	2.3	1.3	1.9	1.1	1.1	0.02	2.8
1960	79	1.1	67	1.0	0.73	0.96	1.3	1.6	0.19	2.6
1961	67	0.47	61	0.67	0.05	0.13	0.59	2.1	0.11	0.93

estimate of human exposure is not available now, and probably will not be for many years to come. However, based on present experience, the avenues of human exposure considered in this report are believed to include all significant or potentially significant mechanisms of exposure resulting from radionuclide discharge to the Clinch River.

Critical Organs Considered

In a detailed analysis it is often necessary to calculate the dose for many organs for which the dose may reasonably be expected to be a maximum or to be in excess of the prescribed limits. To reduce the number of calculations, an insight concerning the potentially critical organs may be obtained by considering the type and concentration of radionuclides released, the maximum permissible concentration in water $(MPC)_W$ for these radionuclides, the potentially significant avenues of exposures, and the type of individual under consideration. From previous estimates it is apparent that the more important exposure pathways are those contributing to internal sources. Based upon these considerations, the organs selected for analyses include bone, gastrointestinal tract, thyroid, gonads, and total body. The bone and total body are reasonable selections when Sr^{90} and Cs^{137} are released and when dose by immersion in contaminated fluids is possible. The increased quantity of Ru^{106}, entering the surface water in 1960 and 1961, and the immersion dose suggested the GI tract. The genetic dose is of particular concern for exposure of a population and, therefore, is included although it can be estimated only approximately as equal to the total body dose, i.e., equal to the average dose in other soft tissues. Finally, the release of I^{131} implicates the thyroid, especially when the child is considered.

The fraction of $(MPC)_W$ attained for the case of internal dose was calculated according to the recommendation of the ICRP.[11] For a mixture of invariant composition and based on a particular organ, x, the fraction of $(MPC)_W$ that is attained is given by:

$$\sum_i \frac{P_{wi}}{(MPC)_{wi}^x} \qquad (1)$$

where

P_{wi} = the concentration of the particular radionuclide in water, and

$(MPC)_{wi}^x$ = the maximum permissible concentration of the particular radionuclide in water for the organ and individual of interest and for continuous exposure.

When the value of expression (1) is less than or equal to 1, the exposure is not in excess of permissible limits. This formulation neglects the dose due to external sources, but the external dose will be estimated separately in this report.

The values of P_{wi} are average values, the period of averaging being 1 year according to the recommendations of ICRP, NCRP, and FRC. All MPC_W values used for data relating to the Clinch River are taken as one-tenth the occupational MPC_W values for continuous exposure. To obtain MPC_W values relating to the Tennessee River, the MPC_W for continuous occupational exposure has been reduced by a factor of one-hundredth for whole body as the critical organ and by one-thirtieth with thyroid, bone, and GI tract as the critical organs.

If the fraction of MPC_W calculated from equation (1) is multiplied by the appropriate annual dose rate permitted in the particular organ of interest, an annual dose rate is obtained. A careful interpretation of such values is necessary, since the calculated dose only applies to a long-term and stable situation. The MPC_W values are set by the requirement that the dose rate (rems/week) after 50 years of exposure shall not exceed a recommended limit. During a 50-year exposure period, equilibrium is reached by most of the radionuclides, because their effective half life is short compared to 50 years. However, in the case of Sr^{90}, the allowable annual dose rate is reached only after 50 years of continuous exposure to the MPC. For this reason, calculation of actual dose received by ingestion of known concentrations of radionuclides is desirable.

As a second interpretation, the calculated dose rate may be considered as a "dose commitment" meaning the dose that will be received during the next 50 years due to an exposure ot one week with P_{wi} determined for that period. Actually, the dose delivered after various times following the intake period depends upon the effective half life of the isotope involved.

Because the MPC's which enter into the calculations have been estimated on the basis of so-called "standard man," the dose really represents only that which would be received by a person of physical characteristics and habits resembling standard man. Thus, the doses estimated should be considered as average values for typical adult individuals. Very little is known at the present time concerning differences in metabolic rates or processes of children and adults

as they relate to important radionuclides. Dose correction factors

that take into account differences due to intake and organ size can

be estimated,[22,30,31,32] but in this report it is not possible to

make any adjustment on this basis.

In the case of the gastrointestinal tract, the calculation of

the MPC is based on the assumption that the wall of the tract will

receive half the dose delivered to the contents of the tract. To a

very large extent this dose will be proportional to the concentration

of the radionuclide in the contents of the tract, but it will not

vary greatly with the mass of the contents or with the diameter of

the tract. Thus no very significant correction is necessary so

far as the masses of the organ or contents are concerned. Assuming

the tract is always full and that the residence time is short

compared to the half-life of the radionuclides of interest, the

dose received will not be changed significantly as residence time

varies. This leaves the concentration of the radionuclide in the

contents of the tract, and, hence, the dietary composition as the

only variable of significance.

The ratio

$$\left(\frac{\text{Intake of Water}}{\text{Weight of Contents of GI Tract}}\right)_{\text{age}} \bigg/ \left(\frac{\text{Intake of Water}}{\text{Weight of Contents of GI Tract}}\right)_{\text{standard man}}$$

would seem to be appropriate correlation factor to apply here. No

data have been found on the variation of the weight of the contents

of the GI tract with age. It is hoped that these data will be

found before completion of the report.

Radioactivity of River Water in Terms of MPC$_W$

Table 17 gives the fraction of MPC$_W$ of the river water calculated by using the average concentration of the various radionuclides for each year where such data were available. As explained previously (page 92), all MPC$_W$ values used for data relating to the Clinch River are taken as 1/10 of the occupational MPC$_W$ values for exposure during the entire week (168 hours). To obtain MPC$_W$ values relating to the Tennessee River, the MPC$_W$ for continuous occupational exposure (168 hours/week) has been reduced by a factor of 1/100 for whole body as critical organ and by 1/30 for thyroid, bone, and GI tract as the critical organs. These values are suggested by ICRP for application to exposure of people living in the neighborhood of a nuclear energy plant, and for the average exposure of the population-at-large, respectively. If the fraction of MPC$_W$ given in Table 17 is multiplied by the appropriate maximum permissible dose rate an annual dose rate is obtained. However, it must be borne in mind that in the case of the radionuclides of long effective half-life, this annual dose rate will be attained only if occupancy continues for many years.

As mentioned above, one can interpret the annual dose rates obtained by the use of Table 17 as a dose commitment for the future, i.e., dose that will be delivered sometime during the next 50 years if life extends that long. The unit is then rem to be delivered during the next 50 years per year of occupancy, not rem/year. Since the MPC values are based on data for a "standard man," either interpretation should be considered to represent the exposure of an "average" or typical adult. Both the FRC and the ICRP allow a value of 3 times the average dose as a practical maximum to

Table 17. Fraction of MPC in Water from Clinch and Tennessee Rivers

Year	Clinch River Mi 14.5				Tennessee River Mi 465.5			
	Bone	G.I. Tract	Total Body	Thyroid	Bone	G.I. Tract	Total Body	Thyroid
1949	0.30	0.0043	0.076	0.021	0.11	0.0016	0.094	0.0077
1950	0.065	0.0022	0.016	0.0043	0.029	0.0010	0.025	0.0021
1951	0.052	0.0017	0.013	0.0038	0.026	0.00087	0.022	0.0019
1952	0.18	0.0015	0.044	0.0098	0.081	0.00069	0.068	0.0045
1953	0.35	0.0018	0.087	0.015	0.16	0.00053	0.13	0.0053
1954	0.51	0.0032	0.13	0.022	0.17	0.0011	0.15	0.0074
1955	0.22	0.0037	0.055	0.0099	0.10	0.0019	0.086	0.0047
1956	0.23	0.0042	0.060	0.010	0.11	0.0020	0.097	0.0051
1957	0.15	0.0024	0.037	0.0063	0.062	0.00099	0.052	0.0027
1958	0.30	0.0031	0.075	0.013	0.14	0.0015	0.12	0.0077
1959	0.20	0.021	0.050	0.0084	0.070	0.0075	0.060	0.0030
1960	0.070	0.050	0.018	0.0037	0.030	0.021	0.026	0.0016
1961	0.053	0.048	0.014	0.0027	0.020	0.019	0.017	0.0010

provide for the variation of dose in a homogeneous population group. This is to say that among adults or children, of like age and exposed to the same environmental situation, there will be a considerable spread of doses actually received, but it is assumed that only a small fraction of the group will receive more than 3 times the average value.

Estimated Radiation Dosages

Drinking Water

Estimates of the fraction of maximum permissible dosages received from drinking Clinch River and Tennessee River water are based on calculated concentrations of radionuclides in the raw water. This approach is conservative because it assumes that there will be no reduction of radionuclides in the water by water treatment before drinking; and it makes no allowance for the small portions of the radionuclides released that are in the bottom sediments and would not be expected to enter raw-water intakes. Future calculations may consider radionuclide removals by water plants and bottom sediments, but the data now available do not warrant this refinement.

To represent estimated dosages for the Clinch and for the Tennessee Rivers, two reference stations were selected, viz., CRM 14.5 and TRM 465.5. The fraction of MPC_W that would be attained by drinking Clinch River water and Tennessee River water from these two locations is given in Table 17. Values at CRM 14.5 represent the fraction of the continuous nonoccupational MPC_W for persons living in the plant vicinity that would be attained, and values at TRM 465.5 represent the attained fraction of MPC_W for the average population at large.

Inherent in the calculation of these fractional values is the assumption that exposure is continuous for a period of 50 years to the mixture of radionuclides that is present during the particular year. For the mixtures of radionuclides in the raw water, estimated exposure to the bone constitutes a greater fraction of the maximum permissible limit than does the calculated exposure to the other body organs. This is attributable to the Sr^{90} that is released. The largest fraction of bone dose attained was 0.51 (51%) for the 1954 concentrations, assuming that the same concentrations continued for 50 years. Applying the most restrictive FRC limit of thyroid dose (for the average child of the population at large which is one six-hundredth of the continuous occupational exposure), the fraction of MPC_w that would be attained at CRM 14.5 is less than 0.04 or 4%. The increase in internal dose to the GI tract for 1960 and 1961 is due to the increased release of Ru^{106}.

Immersion in Contaminated Water

Due to the presence of radionuclides, the river will act as a source of radiation to persons engaged in swimming, boating, fishing and water skiing. Since direct measurements of immersion dose rate are unavailable, it is necessary to calculate the dose rate by considering the radionuclide composition of the water.

The immersion dose calculation assumes the body is in the center of a sphere and receives equal quantities of radiation from all directions. The external exposure from beta radiation may be calculated by means of an equation recommended by Morgan.[33]

With certain reasonable assumptions this expression in units of rad per day is simplified to:

$$\text{Beta Dose Rate} \quad = \quad 51.2 \, QE_i \tag{2}$$

where

$$Q \quad = \quad \mu c/g \text{ of water, and}$$

$$E_i \quad = \quad \text{effective absorbed energy per disintegration}$$

An empirical formula was used to estimate the average effective absorbed energy of a beta disintegration.[30]

$$E_i \quad = \quad 0.33 \, \text{Em} \, f \left(1 - \frac{\sqrt{z}}{50} \right) \left(1 = \frac{\sqrt{\text{Em}}}{4} \right) \tag{3}$$

where

$$\text{Em} \quad = \quad \text{maximum energy of type considered}$$

$$f \quad = \quad \text{fraction of disintegrations at a particular energy,}$$

$$z \quad = \quad \text{atomic number}$$

The penetration distance in water or tissue of the most energetic beta particle from the radionuclides involved is about one centimeter. Therefore, the beta radiation dose to the surface of a large body immersed in the contaminated water is partially excluded, and is effectively one-half of that calculated by equation (2).

The external exposure from gamma radiation may be calculated by means of a similar formula,[33] for which the simplified expression in units of rad per day is:

$$\text{Gamma Dose Rate} \quad = \quad 51.2 \, Q \, \text{Em} \, f \tag{4}$$

in which the terms Q, Em and f are the same as in equations (2) and (3). In each instance where some latitude is allowed in the assumptions, a conservative approach is taken. Therefore the computed dose

rates would be expected to be overestimated.

Where the water contains a mixture of radionuclides, it is
necessary to calculate the dose rate associated with each radio-
nuclide. The total dose rate is simply the sum of the individual dose
rates. Decay schemes presented by Blomeke and Todd are used in the
calculations.[34] The dose-rate values for beta and gamma respectively are
one-half (50 per cent) of the beta dose rate (equation (2)), and
100 per cent of the calculated gamma dose rate (equation (4)).

The immersion dose rates due to beta and gamma radiation at the
two reference stations are listed in Table 18. A maximum dose rate
of 0.027 mrad per day of exposure at CRM 14.5 (1960) is calculated.
The dose rate is a function of radionuclide type and concentration.
Until 1958, the largest fraction of beta dose was associated with Sr^{90}
and the largest gamma dose was generally due to Cs^{137}. Since then,
Ru^{106} has accounted for about 75% of the total immersion dose.

Contaminated Bottom Sediments

Radionuclides associated with solids that have settled to
the bottom of the river can be expected to contribute to the total
radiation dose received by man. Although earlier calculations
assumed complete dilution of fission products in the river, annual
surveys made by the ORNL Applied Health Physics Section have shown
that some of the radionuclides are retained by the bottom
sediments.[35]

Measurements were made at cross sections 2 miles apart in the
Clinch River and approximately 10 miles apart in the Tennessee River.
Measurements consisted of gamma counts obtained with a multiple-GM-tube

Table 18. Immersion Dose Rates in Clinch and Tennessee Rivers

(Units of 10^{-4} mrad/24-hr Exposure)

YEAR	CLINCH RIVER Mi 14.5			TENNESSEE RIVER Mi 465.5		
	BETA	GAMMA	TOTAL	BETA	GAMMA	TOTAL
1949	19	16	35	2.4	2.0	4.4
1950	3.4	5.2	8.6	0.5	0.79	1.3
1951	2.7	2.1	4.8	0.46	0.35	0.81
1952	8	5.0	13	1.3	0.77	2.1
1953	13	2.7	16	2.0	0.41	2.4
1954	20	7.2	27	2.3	0.82	3.1
1955	18	9.9	28	2.8	1.6	4.4
1956	16	18	34	2.6	2.9	5.5
1957	10	9.9	20	1.4	1.4	2.8
1958	16	8.4	24	3.1	1.6	4.7
1959	71	67	140	8.5	8.0	17
1960	170	95	270	25	14	39
1961	160	79	240	21	10	31

detector ("Flounder"), lowered to the surface of the bottom sediments and analyses of mud samples taken at each measurement point.[35] Average concentrations of specific radionuclides in bottom sediments were calculated by averaging all values for the entire study reach of the Clinch River and of the Tennessee River. Cesium-137, Ce^{144}, Co^{60}, and more recently Ru^{106}, were found to be the principal radionuclides associated with these sediments. Reasons for such selectivity are enumerated elsewhere.[36] Major changes in the radioactivity of the bottom deposits were found, but the details of sediment transport must be delineated before conclusions can be drawn about observed changes in radionuclide concentrations.

The "Flounder" is used principally to furnish qualitative information on the build-up of gamma emitting radionuclides in sediments. Construction of the device makes it insensitive to beta radiation. Although the "Flounder" is calibrated routinely with a sealed radium source (as a stability or sensitivity check), the complex spectrum of gamma rays from both the contaminated sediments and the radium source prevents a direct determination of exposure dose by use of this instrument. Estimates of exposure dose can be made, but the limitations of such data must be recognized (Tables 19 and 20).

In a general way, the measurements in the Clinch River reflect the quantity of Cs^{137} and Co^{60} released each year. Maximum readings in the Clinch River (generally at CRM 8.3) were larger than the average readings by a factor of 1.9 ± 0.09; similarly, the ratio in the Tennessee River was 1.8 ± 0.2. For the purpose of estimating the radiation dose to man, calculations of dose were made by using the average radionuclide composition of the sediments. It was assumed

Table 19. Estimated Radiation Dose Rates from Contaminated
Sediments in Clinch River

Measured[a] (10^{-2} mr/24-hr)			Calculated (10^{-2} mrad/24-hr exposure)			
Year	Average	Maximum	Beta	1/2 Gamma[c]	Total	Attenuated[b] 1/2 Gamma[c]
1951	39			90		
1952	88			320[d]		
1953	53			160[d]		
1954	57	110	60	160	220	9.5
1955	60	110	130	180	310	11
1956	130	260	300	630	930	35
1957	96	180	180	460	640	24
1958	100	200	210	360	570	19
1959	160	280	450	710	1160	39
1960	150	280	510	460	970	25
1961	95	170	530	290	820	15

[a] In units of 10^{-2} mr/24-hr exposure as measured by the "Flounder."

[b] Attenuation through 3 ft of water.

[c] One-half of total gamma dose from infinite source.

[d] Estimated from correlation relationship.

Table 20. Estimated Radiation Dose Rates from Contaminated
Sediments in Tennessee River

	Measured[a] (10^{-2} mr/24-hr)		Calculated (10^{-2} mrad/24-hr exposure)			
Year	Average	Maximum	Beta	1/2 Gamma[c]	Total	Attenuated[b] 1/2 Gamma[c]
1951	13					
1952	22					
1953	23					
1954	19	30	22	50	72	3.0
1955	26	43	60	68	128	4.2
1956	36	69	65	110	175	6.1
1957	33	58	37	80	117	4.2
1958	35	63	55	62	117	3.5
1959	30	63	48	56	104	3.1
1960	33	49	75	61	136	3.3
1961	26	48	95	54	149	2.8

[a]In units of 10^{-2} mr/24-hr exposure as measured by the "Flounder."

[b]Attenuation through 3 ft of water.

[c]One-half of total gamma dose from infinite source.

that this average composition was distributed uniformly in an infinite

source. To assume an infinite source containing the maximum concentration

of radionuclides observed seems overly conservative. Further, it was

assumed that the individual would be exposed to one-half the

immersion dose of beta particles and to one-half the immersion dose

of gamma emissions (i.e., from one-half a sphere). Such an assumption

is reasonable since the individual receiving the dose is likely to

be standing on or floating above the contaminated sediments. Normally,

only the feet would be subjected to the total beta and gamma dose rate.

Calculated dose rates from bottom sediments in the Clinch River

and Tennessee River are listed in Tables 19 and 20. The beta dose

rate was taken as one-half the value determined by use of equation (2)

and the gamma dose rate as one-half the calculated value by

equation (4). Since the source is not infinite in extent, the

calculated values give a larger estimated dose rate than that actually

available. Accordingly the largest bottom sediment dose rate of

12 mrad per day of exposure (1160×10^{-2}) would have occurred in 1959,

and was divided as 0.4 beta and 0.6 gamma radiation. The percentage

contribution of specific radionuclides to the beta and gamma dose rates

shows that the total rare earths, Cs^{137}, and more recently Ru^{106}, are

the principal contributors to beta dose rates, and Co^{60} and Cs^{137}

account for the largest fraction of gamma dose rates.

Since bottom sediments are generally covered by water, the

gamma dose rate to the gonads of an individual standing on the river

bottom would be reduced by attenuation. An average attenuation

coefficient for water was calculated by weighing both the fraction of

time a photon of a given energy was emitted by a particular radionuclide

and the fraction each radionuclide contributed to the total loading
of the bottom sediments. The fraction of dose remaining is graphed
as a function of the depth of water shielding (Fig. 22). The estimated
gamma dose rates after attenuation through 3 feet of water are listed in
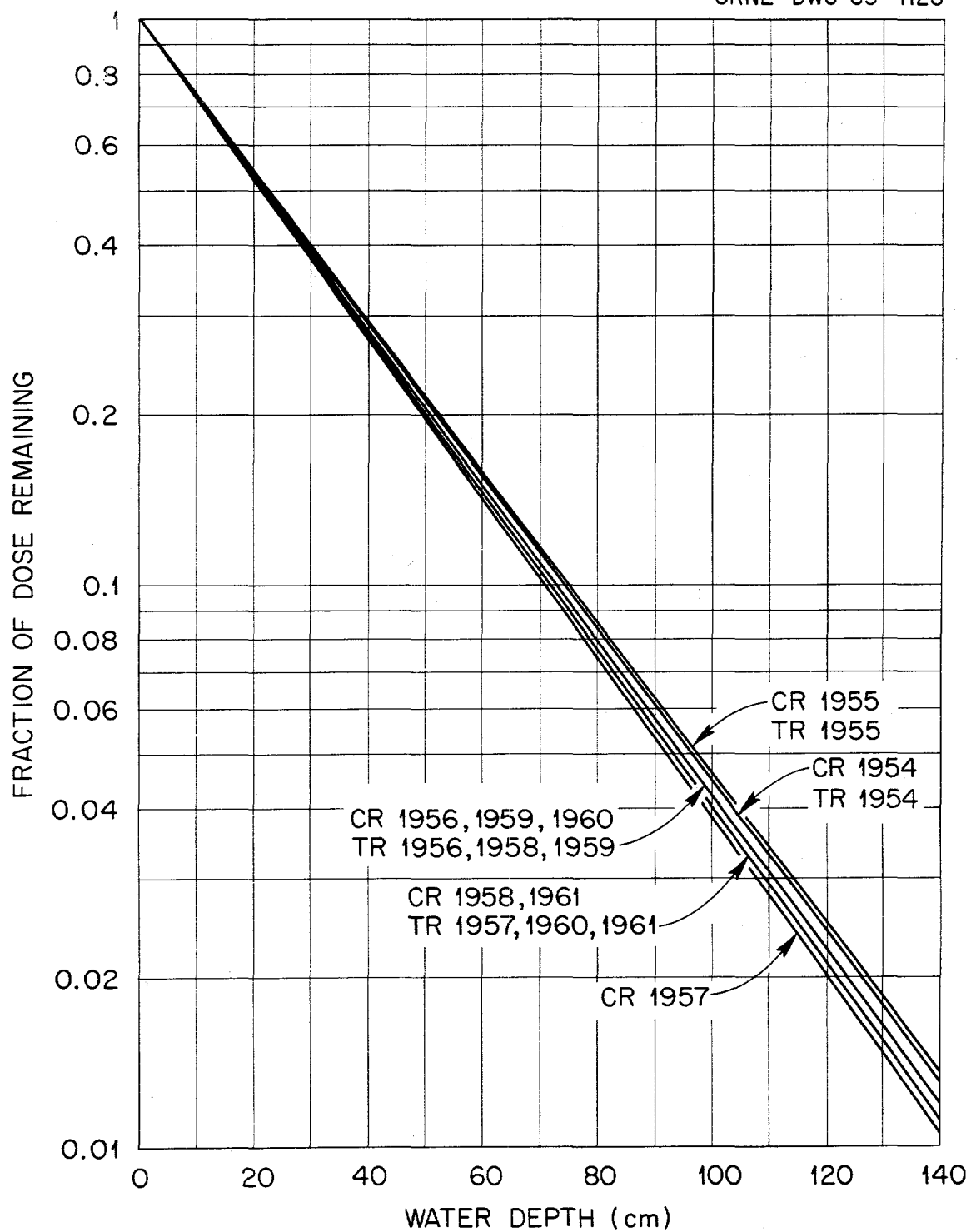Tables 19 and 20.

Fig. 22. Attenuation of Bottom Sediment Dose in Clinch River and Tennessee River.

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